L

La Caille, Nicolas-Louis de. Born in Rumigny (Ardennes) and baptized on 29 December 1713 (Glass 2013, 5), Nicolas-Louis de La Caille was the son of an army officer and orphaned at seventeen. With the assistance of his patron, Louis Henri de Bourbon, he entered the Collège de Lisieux in Paris, where he received both religious and scientific training. But La Caille chose a secular life and focused on his interests in astronomy, optics, and mathematics. Recommended to Jacques Cassini (II) (Mascart 1919, 240), La Caille worked with him first at the Paris Observatory and then on the geodetic survey of the northern coast of France, and with César-François Cassini (III) de Thury and Giovanni Domenico Maraldi around Cherbourg, Nantes, and Bayonne (1738) (Glass 2013, 13). He subsequently participated in verifying the meridian (1739–40), later compiling the *Nouvelle carte qui comprend les principaux triangles qui servent de fondement à la description géométrique de la France* (probably 1745; see fig. 19). Prepared under the supervision of Cassini III and Maraldi, the map provides a still more refined and modern-looking outline of France than does the *Carte de France corrigee* (see fig. 625), presented to the Académie in 1684 (published in 1693). Sailors profited little from this effort, however, for marine charts still did not use geodetic networks in their construction (Chapuis 1999, 105). Appointed professor of mathematics at the Collège Mazarin in November 1739, La Caille installed an observatory there in 1742 and then a larger one in 1748 (Glass 2013, 15–17) and taught astronomy. He became a member of the Académie royale des sciences in 1741.

Having called for a scientific expedition to the Cape of Good Hope, with government support he embarked upon a vessel of the Compagnie des Indes commanded by Jean-Baptiste-Nicolas-Denis d'Après de Mannevillette; the Compagnie was motivated by the loss of one of its vessels at the Cape des Aiguilles in January 1750. From 1749 d'Après de Mannevillette had been regularly using lunar distances to calculate longitude at sea, the first French navigator to do so; La Caille had helped lay new theoretical foundations for this practice as early as 1741. During the voyage from the Atlantic to the Indian Ocean (November 1750 to June 1754), La Caille and d'Après de Mannevillette together took lunar measurements for longitude as far as the Île de France (Mauritius) and Île Bourbon (Réunion); La Caille also determined latitudes (fig. 430). He then returned to the Cape of Good Hope, where he stayed from April 1751 to March 1753. La Caille was the first to propose the preparation of lunar tables that would simplify the method of lunar distances for use by common navigators, as outlined in a *mémoire* read in his absence by Maraldi at the Académie royale des sciences in 1754 (Boistel 2001, 1:335). La Caille further undertook a short geodetic triangulation of the length of a degree at the Cape, verifying the symmetry of the value of a degree of latitude in the Southern Hemisphere as compared to the measurements of the meridian carried out from 1735 by order of the Académie.

Even though a certain number of points had been plotted astronomically, the hydrographic contribution of the voyage was less spectacular in terms of method. For naming a large number of stars and constellations in the southern sky (see figs. 165 and 183), La Caille was elected to the Royal Society (17 March 1760) and a number of other European scholarly societies. He was first and foremost a great astronomer, one of the most prolific of the century and an experienced teacher. After his oceanic voyage, he contributed to the simplified edition of the *Nouveau traité de navigation* by Pierre Bouguer (1753; reedited 1760). He died in Paris on 21 March 1762, leaving a considerable number of printed works in the field of astronomy.

OLIVIER CHAPUIS

SEE ALSO: Celestial Mapping: France; Compagnie des Indes (Company of the Indies; France); Constellations, Representation of; Geodesy and the Size and Shape of the Earth; Geodetic Surveying: France; Longitude and Latitude; Paris Observatory (France)

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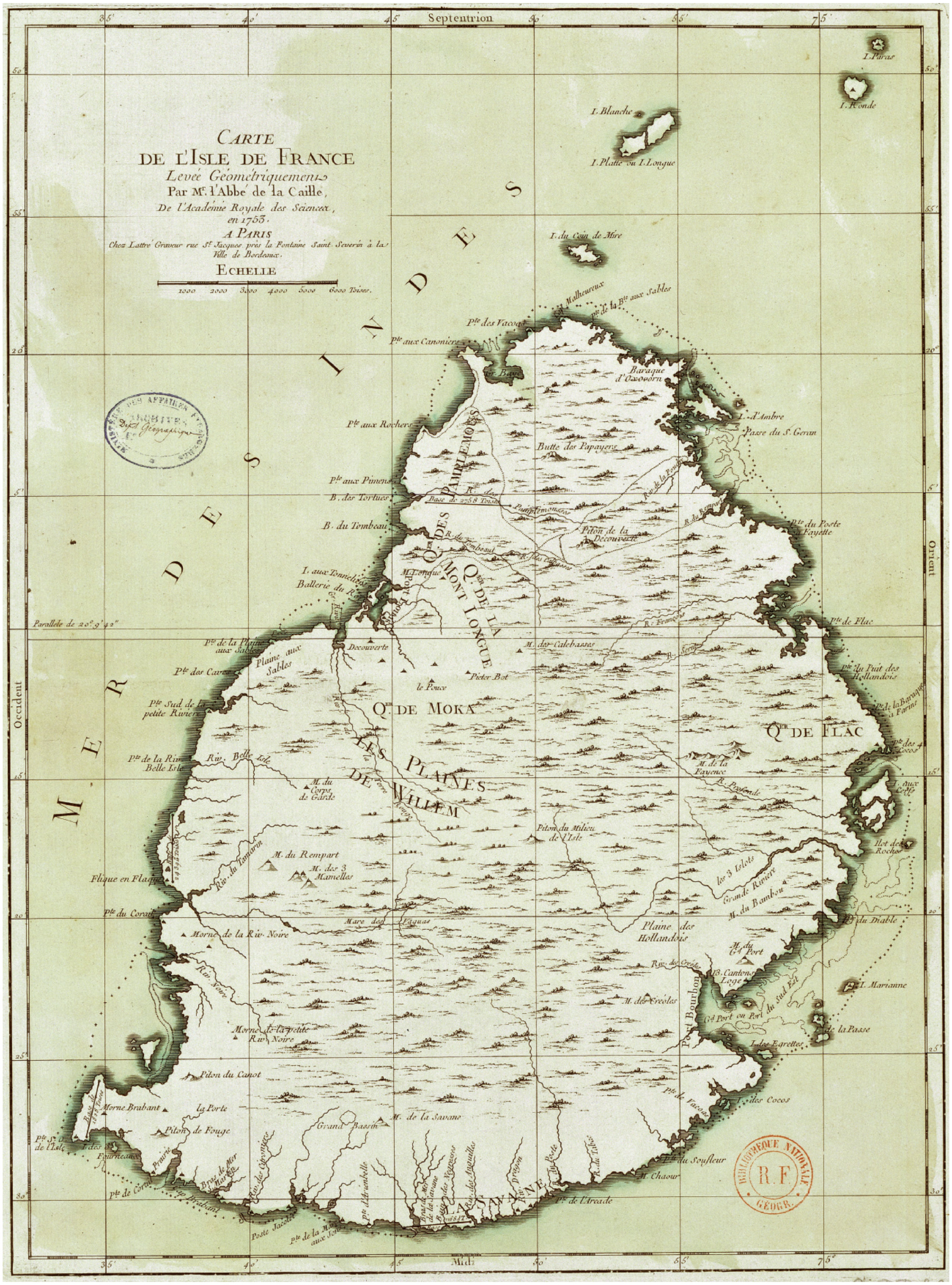

FIG. 430. NICOLAS-LOUIS DE LA CAILLE, *CARTE DE L'ISLE DE FRANCE LEVÉE GÉOMÉTRIQUEMENT* (PARIS, [1754]). First edition, engraved map on one sheet, ca. 1:106,000. In 1753, La Caille fixed the latitude and longitude of Île de France (Mauritius). He surveyed the island trigonometrically, and four baselines are indicated around the western and southern coastlines, ranging from 1800 to 2750 toises in length. Although the map is dated 1753, it did not appear until after La Caille's return to France in June 1754.

Size of the original: 47 × 34 cm. Image courtesy of the Bibliothèque nationale de France, Paris (Cartes et plans, Ge DD 2987 [8426]).

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La Condamine, Charles-Marie de. The contribution of Charles-Marie de La Condamine (1701–74) to cartography in the eighteenth century rests predominantly with his famed *Carte du cours du Maragnon* (fig. 431), a map that Jean Le Rond d'Alembert referred to as "more exact than any that had preceded it" (d'Alembert 1751, 1:318). Upon his return from the Franco-Hispanic geodetic expedition to equatorial South America, La Condamine's cartographic revelation of a previously poorly known swath of the continent earned him more prominence than all of his geodetic measurements in Quito combined. Nevertheless, the cartographic methodology he employed while descending the Amazon was similar to that which he had employed as a member of that geodetic mission, involving the astronomical observation of Jupiter's satellites and geometrical triangulation as well as depth sounding.

Published in 1745 in conjunction with the *Relation abrégée d'un voyage fait dans l'intérieur de l'Amérique Méridionale*, the *Carte du cours du Maragnon* took its place among a series of important maps of South America from the seventeenth century that represented the full course of the Amazon River. These included *Le Perou et le cours de la Riviere Amazone* (1656); *Le cours de la riviere des Amazones* (1680) by Nicolas Sanson, produced to accompany the *Relation de la riviere des Amazones*, translated by Marin Le Roy de Gomberville (1682), from the Spanish original of the Jesuit father Cristóbal de Acuña; and the set of maps produced early in the eighteenth century by the Jesuit Samuel Fritz, including one manuscript map that La Condamine himself brought back from Quito and deposited in the king's library in Paris. La Condamine's Amazonian map was a fusion of two contemporaneous cartographic methods. On the one hand, La Condamine used the instrumental methods of on-site surveying and astronomical observations to measure, quantify, order, and situate a complex hydrological system; on the other, he employed the off-site compilation techniques of small-scale geographic mapping that sought to create a holistic expression of a distant and little-known world by collecting diverse data and solving mysterious puzzles of various descriptive languages and the mathematics of space, time, and distance, whose resolution had eluded previous explorers. In this sense, the map bears a symbolic similarity to Denis Diderot and d'Alembert's *Encyclopédie* (1751–72), as it sought to produce a complete map of a river system that lay at the fringes of known European geographic knowledge.

FIG. 431. CHARLES-MARIE DE LA CONDAMINE, *CARTE DU COURS DU MARAGNON OU DE LA GRANDE RIVIERE DES AMAZONES*, 1745. La Condamine created this map of the Amazon River and its region through a combination of on-site observation and the compilation of relevant data. Size of the original: ca. 13 × 30 cm. Image courtesy of the Bibliothèque nationale de France, Paris (Cartes et plans, Ge DD 2987 [9542]).

The *Carte du cours du Maragnon* was also significant in La Condamine's use of it as a springboard for his own recognition within the Académie royale des sciences. By rhetorically critiquing earlier cartographic representations of the Amazon, he heightened his own credibility and sought to portray himself as a reliable *voyageur-philosophe* in the eyes of the scientific establishment. The map was explicitly designed to be viewed alongside and to supplement his travel narrative, the *Relation abrégée*, in which he explained in obsessive detail his steps to reveal equatorial South America to European eyes with an astronomical precision previously unknown in those regions.

Similarly, La Condamine played a fundamental role in publishing one of South America's most important eighteenth-century maps, the *Carta de la provincia de Quito y de sus adyacentes*. Its author, Pedro Vicente Maldonado, who was named governor of the Esmeraldas province in the Viceroyalty of Peru, had died without completing his map, and La Condamine stepped in to finish Maldonado's work, taking credit for much of the resulting cartographic representation.

NEIL SAFIER

SEE ALSO: Geodesy and the Size and Shape of the Earth; Geodetic Surveying: (1) Enlightenment, (2) France; Lapland and Peru, Expeditions to

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Lambert, Johann Heinrich. Born 26 August 1728 in Mulhouse (in Alsace, then part of Switzerland), Johann Heinrich Lambert was the son of a tailor. He was almost entirely self-taught and became a mathematician, astronomer, physicist, and philosopher. He began his career as an office clerk and bookkeeper and later as a secretary for Johann Rudolf Iselin, a lawyer in Basel. From 1748, he taught privately in the house of Count Peter von Salis in Chur. There he used the family's large library for his own studies in mathematics, physics, meteorology, astronomy, mechanics, metaphysics, and rhetoric as well as learning several foreign languages. In 1750 Lambert started meteorological observations; by 1753 he had taken barometric and thermometric measurements of the heights of mountains in the region of Chur, and in 1755 he began publishing his essays in *Acta Helvetica, physico-mathematico-anatomico-botanico-medica*. Starting in 1756 Lambert undertook scientific travels with his pupils to Göttingen and several more German cities, as well as Utrecht, Paris, Turin, and Milan. In 1764 he went to Berlin, where Friedrich II appointed him a regular member of the Akademie der Wissenschaften. In 1770 he became a government architect and surveyor of buildings, supervising rural civil engineering.

Lambert made fundamental contributions to four disciplines: mathematics, astronomy, physics, and philosophy. His importance for cartography resulted from his mathematical writings dealing with practical geometry and perspective, the theory of infinite series and the theory of functions, infinitesimal calculus and probability calculus, and non-Euclidean geometry. He invented the proportional pair of compasses in 1768 and constructed a calculating machine. His entries in a monthly notebook, in which he listed his scientific activities beginning in 1752, demonstrate his study of geographical maps, map projections, the shape of the earth, the surface of the spheroid, and the relationship of the length of the pendulum and gravity.

In the 1760s Lambert published two articles that considered problems of surveying and of flattening the surface of the earth (1763, 1765). His main publication in cartography was "Anmerkungen und Zusätze zur Entwerfung der Land- und Himmelscharten" (Lambert 1772), in which he compared several extant map projections and enlarged them using new methods derived from the calculus. Today several projections bear his name, though he himself did not name them. Their construction and naming are explained by John Parr Snyder (1993, 76–94). Moreover, three of his new projections are among the most common projections still used: the Lambert conformal conic (see fig. 645), the transverse Mercator (see fig. 644), and the Lambert azimuthal (or zenithal) equal-area. Two others offer specialized use: the Lagrange projection, primarily for world maps; and the Lambert normal cylindrical equal-area. Finally, two are rarely used, but are of mathematical interest: the transverse cylindrical equal-area and the Lambert conical equal-area.

By offering these unparalleled achievements in the theory of map projections, Lambert became the founder of modern mathematical cartography. He died 25 September 1777 in Berlin and was held in great esteem by his contemporaries as well as mathematicians a full century later.

INGRID KRETSCHMER

SEE ALSO: Projections: Geographical Maps; Science and Cartography

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Landscape, Maps, and Aesthetics. A case for the interplay between the artistic consideration of landscape and the role of maps and views may be made through the study of a series of debates, exchanges, and parallels between the cultures of cartography and the art world of Georgian Britain, focusing on particular artists and works, in particular those of Paul and Thomas Sandby. The realms of both art and cartography expanded greatly in the period and enjoyed high cultural esteem as well as commercial popularity, not least for their patriotic worth. This account emphasizes the contentious status of topographical knowledge, as visualized or pictured in maps and plans, landscapes and portraits, views and vignettes, paintings and prints. Of course, the results of such detailed analysis cannot be taken as representative of all of Enlightenment Europe, yet they can promote further studies of the complex intersection of cartography and formal aesthetics elsewhere in Europe.

The term "map" became a key word of critique in British art and aesthetic theory from the later eighteenth century, in a period when both the commercial power and social esteem of cartography escalated in various forms and affiliations. The culture of cartography emerged in artworks of various intersecting genres: military surveys, estate prospects, garden plans, coastal marine charts, town plans and views, and family portraits showing educational cartographic artifacts. The art world was never far from the world of cartography.

Maps and cartography, however, were not accepted as being part of the art world. In the course of a lecture delivered to students of the Royal Academy, following his appointment as professor of painting in 1799, Henry Fuseli railed against the debasement of art by commerce and the reduction of paintings to items of "fashionable furniture," whether portraiture depicting family likenesses and affective relations, not noble men and ideas, or "that kind of landscape which is entirely occupied with the tame delineation of a given spot . . . what is commonly called Views." These views, "if not assisted by nature, dictated by taste, or chosen for character," argued Fuseli, "may delight the owner of the acres they enclose, the inhabitants of the spot, perhaps the antiquary or the traveller, but to every other eye they are little more than topography." No doubt Fuseli's rhetoric was sharpened by the fact that the Royal Academy's premises on the Strand were surrounded by the shops of London's leading mapsellers. Dealers and galleries selling old master paintings and prints were close to shops selling topographical prints and illustrated books and magazines featuring maps and views. Fuseli favored the classically styled Italianate art of seventeenth-century European masters, such as Claude [Lorrain] and Nicholas Poussin, and its imitation by eighteenth-century British painters, such as Richard Wilson—high-minded, idealized landscape art that "spurns all relation with this kind of map-work" (Fuseli 1831, 2:216–17).

Fuseli's attack on topography may well have been targeted at the professor's fellow academicians, the Sandbys. His lecture was first given at a moment when Paul Sandby's critical stock among connoisseurs was low (Farington 1978–98, 1:220). "Map-work" was a pointed slight to deprecate the practice of two men whose careers began when working as draftsmen for the military and whose formative experience with the surveying and making of maps, plans, and perspectives shaped their view-making for civilian clients and customers throughout long and influential careers. The slight served to reduce the cultural and geographical scope and intensity of the Sandby brothers' topographical art, whether executed individually or in collaboration, as it ranged across a variety of genres and styles as well as sites, regions, and terrain, combining the observed and the imagined, narrative and description, social commentary and documentary delineation (Bonehill and Daniels 2009b).

Yet Fuseli was also fighting something of a rearguard action against the popularity achieved by topographical representations by the end of the eighteenth century. In addition to a popular demand for cheaper cartography, there was also an increasing patriotic recognition of the fine quality of map production, the artistry of map drawing and engraving, in a nation that was conscious of lagging behind its continental rivals in the scope and skill of surveying and mapmaking (Alfrey 1990; Daniels 1993). A new culture of cartography modernized long-standing traditions of topographical knowledge. Maps at several scales and in many genres were part of the expanding visual field of topography, along with various kinds of view, vista, vignette, plan, prospect, and perspective. Imagery was central to the recording and making of natural knowledge and the historic record, placing plants and animals, ruins and monuments within the landscape and the connections of a wider world. For natural philosophers committed to knowledge as discovery, maps were part of the valorization of visual imagery as an empirical and theoretical form of knowledge, collating factual information and providing ideas of the interaction of land and life, nature and culture (Walters 1988; Klonk 1996; Smiles 2000).

A growing range of optical instruments charted the structure and scenery of the terrestrial world, extending the power of eyewitness testimony, and powerful reflecting telescopes revealed a new world of topography to be mapped on the moon. Metaphors of mapping and surveying for forms of elevated and comprehensive understanding migrated from religious to secular discourse to characterize enlightened knowledge of the material world (Livingstone and Withers 1999; Withers 2007).

If the fine art academies of Europe looked down on topography, it remained central to courtly and aristocratic culture. Topography enjoyed noble patronage in Britain, notably that of the king, George III, who built an extensive collection of civilian, military, and naval topographical works; scale models as well as works on paper; plain and decorative images, from fine presentation copies of maps and plans to views illustrating almanacs and theater tickets. On the one hand, this royal enthusiasm was traditionally princely, a territorial form of statecraft above political faction. On the other hand, it was a popular, highly commercial form of citizenship. Among the enthusiasms the king shared with his subjects, George III purchased prints and illustrated books, took lessons in drawing, and made views, on one occasion submitting works to the annual public exhibition of the Society of Arts in the name of his drawing master (Barber 2003, 2005; Gerbino and Johnston 2009, 131–51).

More than a style of depiction, topography was a collective form of cultural practice, an enterprise involving professional and amateur artists, antiquarians and naturalists, engravers and publishers, men and women of all ages. They gave and took lessons; collected, lent, and exchanged letters, books, maps, plans, drawings, and prints; and went on group tours to sketch places on the ground. As a mode of socialization, topography was part of the production of "politeness" as an ideology, an expression of the vaunted liberality of British society, serving, at least in principle, to connect people of many ranks, from professional to aristocratic families. Topography was also an increasingly commercial venture, with the market for descriptions of the country's localities buoyed by the popularity of domestic tourism among the leisured and moneyed classes, patriotically so during the Napoleonic Wars when continental Europe was closed to travel, and with it the loss of the classic tradition of taking Grand Tours (Bermingham 2000; Sloan 2000; Myrone 2009).

The academic critique of cartography, particularly its degradation of mapmaking to menial work, draws on a wider European tradition of cultural condescension in eighteenth-century aesthetic theory against the technical transcription of the visible world. The fine arts were esteemed above the mechanical arts, including the mechanical arts of entertainment as well as instruction, such as topographical models and panoramas (Fox 2009, 135–78; Hyde 1988). It was the illusionism as well as accuracy of such mechanical devices that was subject to criticism, a hyper-reality that contrasted with the idealized imagery of classical art. The academic critique effectively fractured the longstanding philosophical framework for art as a synthesis of the liberal-humanist and mechanical arts, conventionally symbolized by the pairing of the palette and the compasses, particularly for landscape art, which had a traditional basis in measurement and mathematical perspective as well as literary and historical knowledge (Nuti 1999). The critique also deliberately marked a distance from much eighteenth-century amateur and professional art practice, which moved between genres of actual and ideal representation or combined them. Moreover, it also overlooked the fact that instruments were manufactured to produce both forms of representation in the field—portable types of camera obscura to transcribe particular detailed views and the so-called "Claude glasses," silvered convex mirrors that transformed specific localities into classically styled abstract looking scenery (Sloan 2000).

In addition to featuring in academic theory, which considered landscape to be a lowly genre compared with history painting (such as scenes from the Bible and classical antiquity), the critique of cartography was central to more modern discourses focused on the external world, for which the very availability of maps (portable ones for practical travel and display versions for visualizing regions and nations) only served to reveal their limitations. So picturesque theorists promoted compositional schemata derived from old master paintings or short-focused views of nooks and crannies: "It is certainly an error in landscape-painting, to comprehend [i.e., to include] too much" pronounced William Gilpin, for "it turns a picture into a map," this to the frustration of practically minded users of his guidebooks who did not realize the illustrations were primarily to illustrate generic principles of landscape composition and could not place where they were (Gilpin 1786, 1:146). In their search for a more personal, sublime engagement with nature, and more high-minded forms of excursion, Romantic writers found that maps comprehended too little. William Wordsworth's poems on Black Comb, a primary station for the Ordnance Survey, describe how a "geographic Labourer pitched his tent" on the summit and a sudden stormy fall of darkness eclipsed "the whole surface of the out-spread map" as he was given "a glimpse. . . . of Nature's processes" (Wordsworth 1978, 429).

As a direct response to Fuseli's condemnation of "map-work," John Britton, an author and publisher of guide books and views, argued that topography was an integral part of the "native talent" of English art, shaping its national character. Britton reclaimed Wilson's art from Fuseli's classical theory by emphasizing the primacy of Wilson's "Topographical views of English scenery" over his "Italian and other foreign views" and historical or mythological "Landscapes, with figures." Like the old masters he imitated, Poussin and Claude, Wilson "delineated views of certain places, and I do not conceive that he is thereby depreciated in the estimation of the impartial critic: yet we have been told that . . . those who practise it [landscape painting] are little better than 'topographers and map-makers'" (Britton et al. 1812, 65–66). While Britton conceded that a few "tasteless" artists might be narrowly descriptive, he was intent on upholding a form of English landscape art for which topography provided a foundational framework, supporting other qualities, including observations of fleeting effects of nature, allusions to literature and mythology, echoes of old master painting, and samples of scenographic entertainment. This aesthetic program is exemplified by the work of Joseph Mallord William Turner; Britton's commentary on an engraving of Turner's view of the ruins of Pope's Villa at Twickenham Bard (1808) describes how the picture portrays its poetic atmosphere and classical allusions in a precise, documentary record of a particular time and place, depicting "the declining sun, and the dilapidated Villa" to show the desecration of a sacred spot (Britton et al. 1812, 20). "Truth is preferable to falsehood; reality is more valuable than fiction," and for Britton, topographical landscape offered a progressive, politically liberal truth of record, not invention, that was accessible to everyone who could walk and see: "It speaks a language to be understood by all persons of every nation and every situation in life; because the scenery of nature is unfolded to all eyes" (Britton et al. 1812, 66).

From 1801 to 1818 Britton and others compiled the most comprehensive and systematic survey of the country's topography, *The Beauties of England and Wales; Or, Delineations, Topographical, Historical, and Descriptive, of Each County*. Each volume was based on a critical review of all existing texts and images and, above all, extensive firsthand field observation, developing a liberal landscape vision that looked well beyond castles and country houses. The series was accompanied by maps of each county and of the main town or city, showing modern structures as well as antiquities. Some of the maps were collected as *The British Atlas* (1810): urban maps displayed plans of new jails and workhouses as well as illustrations of coats of arms and vignettes of medieval gateways; county maps showed coach roads, canals, mineral railways, Roman roads, ancient British camps, and sites of successful excavation. Britton commissioned views from leading architectural draftsmen and landscape artists and trained others in his house on Burton Street, Bloomsbury, which was a new variant of the enterprise of natural history illustration that Sir Joseph Banks ran from his house in Soho Square and the one that antiquarian Richard Gough orchestrated. It amounted to "an informal academy of topographers," even a powerful "Britton school" of art (Lukacher 1999, 6, 29).

Paul Sandby worked for the Board of Ordnance in Woolwich just one day a week so that he had time to pursue a diverse and lucrative career as a professional artist. He accepted commissions from various institutional bodies and individuals and worked as a theatrical scene painter and a drawing master to aristocratic patrons, including the royal family, as well as a printmaker and publisher. Sketching tours and travels out to estates of wealthy patrons expanded Sandby's field of work and vision, with the view from the road providing a wealth of motifs, including country seats and prosperous towns, agrarian land and parks, modern improvements and antiquities. Views of historic architectural remains, rural and urban, often produced in collaboration with his elder brother, appealed to his antiquarian impulse to assemble what history and geography had scattered across Britain and, with many sites vulnerable to "improvement" or demolition, to preserve their existence for posterity. Thomas Sandby's interest in the poetic and historic associations of ruins informed designs he made for Windsor Great Park in his capacity as deputy ranger of this royal landscape; they included grottos and root houses as well as Gothic bridges and towers (Roberts 1997). "Architecture cannot otherwise entertain the mind than by raising agreeable emotions and exciting pleasing ideas" argued the elder Sandby, in his lectures as professor of architecture to the Royal Academy, maintaining that "it may therefore be considered as tending to the same agreeable purposes as painting, sculpture, poetry, music, and other liberal arts." Sandby's architectural theory advocated an expressive form of practice intended "to captivate the Eye, and engage the attention of the Spectator," a painterly and poetic vision of building that in the "laying out Pleasure Grounds" would "produce the most varied and agreeable Scenery." This conception of architecture and landscape as providing "a continual moving Picture," a series of ambient views, shaped both brothers' practice (Sandby ca. 1794, lecture 1, p. 5, lecture 4, pp. 6–7).

In the ambitious London art world of the mid-eighteenth century, keen to raise its academic aspiration and professional independence, estate portraiture proved a contentious genre. Invited in 1764 to portray the newly acquired estate of Philip Yorke, second earl of Hardwicke, Thomas Gainsborough declined, as the subject was beneath his artistic ambition, remarking that "with regard to *real Views* from Nature in this Country, he has never seen any Place that affords a Subject equal to the poorest imitations of Gaspar or Claude," and recommending

FIG. 432. RICHARD WILSON, *VIEW FROM MOOR PARK, TOWARD CASSIOBURY, WATFORD AND ST. ALBANS*, CA. 1765–67. Size of the original: 147.3 × 182.9 cm. Image courtesy of the Zetland Collection.

Paul Sandby as "the only Man of Genius . . . who has employ'd his Pencil that Way" (Gainsborough 2001, 30). Despite this disdain for estate portraiture, commissioned views of aristocratic seats featured strongly in London's earliest public art exhibitions. In a nation state where landed property was the basis of political power and social prestige, Sandby was one of a number of artists who extended the power and scope of estate portraiture in varied and culturally complex views that included natural wonders and antiquities as well as agriculture, industry and commerce, parks, gardens, and mansions. With the growing popularity of touring among all ranks of polite society, estate portraits projected public prospects as well as private views, a picture of the country and the nation at large (Bonehill and Daniels 2009a).

In 1767 Paul Sandby showed two estate portraits at the annual exhibition of the Society of Artists: *Two Views of Wakefield Lodge, in Whittlebury Forest, the Seat of His Grace the Duke of Grafton*. Sandby's views joined other pictures at the exhibition depicting named places on noble estates, ambitious works that ranged across a variety of countryside, depicting a range of sites and estate activities in a number of styles. William Tomkins submitted extensive views of enlarged and improved properties belonging to James Duff, second earl of Fife—his seat in Banff and a shooting lodge in Aberdeenshire—showing with an even light and multiple focal points a well-ordered landscape of plantations, gardens and parkland, arable land and pasture, roads and lanes, all populated with an array of polite, prosperous-looking North Britons. If Tomkins's documentary style lacked the effect connoisseurs looked for in landscape painting, this was supplied in Wilson's *View from Moor Park* (fig. 432). In showing figures surveying the flourishing countryside

FIG. 433. PAUL SANDBY, *NORTHWEST VIEW OF WAKEFIELD LODGE IN WHITTLEBURY FOREST*, 1767. Size of the original: 42.5 × 84.5 cm. Image courtesy of the Yale Center for British Art, New Haven (B1977.14-4648).

adjacent to a house purchased by Sir Lawrence Dundas, Wilson cast his picture in Claudian style, with some antique architectural remains placed in the foreground in the style of poetic landscape gardening (Solkin 1982, 126–29).

Sandby's views of Wakefield Lodge explore the implications of landscape improvements, for the place in question and the country at large. One of the artist's most important patrons, Augustus Henry FitzRoy, third duke of Grafton, was instrumental in Sandby's appointment the following year to the staff at Woolwich. The dukes of Grafton acquired Wakefield Lodge, a former shooting lodge, in 1712 from the Crown and converted the estate into their main seat. They oversaw a comprehensive program of improvement, enclosing common land, amalgamating farms, reforming tenancies, and introducing new methods of agriculture and silviculture. The making of this modern landscape from the customary forest economy was a contentious process, involving protracted conflicts with local people, particularly over game and wood (Riden and Insley 2002, 18–37). Sandby's one surviving drawing is a wide-angled view focused on the house and grounds redeveloped according to a design by William Kent (fig. 433). A smartly dressed equestrian group came upon a ragged rustic couple bundling wood, a potential flashpoint of conflict. Local commoners did not keep politely to the remaining forest; despite the threat of severe punishment, they went into parks at will, even when some attempt was made to regulate this by admitting them only on certain days of the week, as a privilege not a right, which is probably the point of the episode here. This scene of benevolent landownership carries a wider political resonance as a public relations image; Grafton also came into conflict with the Crown for his claims on timber trees, and his entire project of woodland management came to symbolize his political reputation for tyrannical governance (Junius 1772, 2:111–12, 167–69).

As increasingly large and elaborate ornamental parks and gardens were developed for the aristocracy of eighteenth-century Europe, so was the extent and variety of their visual representation. Maps, perspectives, prospects, vignettes, and elevations were produced, sometimes combined to give a series of views on one overall plan. Such plans included both practical construction drawings and finely produced commemorative images that recorded the projection and material progress of these landscapes. Plans enunciated principles as well as recorded places, and some were complex compendia of ideas and images. Garden plans were made in a variety of formats and media, and there were large presentation works of great artistry with elaborate cartouches in watercolor and ink, or fine engravings, to be unrolled like wall maps or placed in large folios. Other cheaper, smaller prints were produced for a wider public, including illustrations for guidebooks, almanacs, and albums of views charting the taste and authority of a country's elite (Harris and Hays 2008; Dubbini 2002, 36–48).

The Sandbys' work appealed to diverse audiences, collectors and patrons, aristocratic and middling, military and civilian, as well as the owners, inhabitants, antiquaries, and travelers Fuseli derided. They were influential in establishing a national style of visual culture for picturing the land and life of Britain, laying out the topographical territory that Fuseli sought to diminish as a fair subject for painting, but which his contemporary opponents, notably Turner, sought to reclaim and develop as a field for modern art.

At the Royal Academy summer exhibition of 1794, Sandby deployed a prospective format for a new form of estate—a suburban property overlooking a factory. The commission was to portray James Whatman II's villa outside Maidstone and his paper mill, a much more extensive building, centrally placed in the picture in the manner of a large mansion (Daniels 2006; Bonehill and Daniels 2009b, 216) (fig. 434). Whatman wove paper of the highest quality that was used for official documents, luxury volumes of literature and topographical prints, manuscript and printed architectural plans and antiquarian illustrations, and maps and charts. Figure 434 is drawn in *gouache* on a large piece of Whatman's paper, the heavily sized kind produced in late autumn when the drying process was slow and controlled by artificial heating, precisely what is shown in the view of the mill with smoking chimneys above the shutters. The picture is a paper landscape in more ways than one, affiliated with a wider culture of work on paper and its culture of documentation and an end product of the process it shows.

Whatman's villa and factory are framed in an extensive, varied, and highly productive-looking landscape, of grazing paddocks, hop gardens, and fruit trees. In the far distance is a ridge of chalk downland whose streams were presumed to give Whatman paper its luster, an exposure of brilliant white marking the main road to London. The foreground is a public road, traveled by a milkmaid and cattle and a single horseman, running to a junction with a major turnpike along which a stagecoach speeds toward the town. The two roads bound

FIG. 434. PAUL SANDBY, *A VIEW OF VINTNERS AT BOXLEY, KENT, WITH MR WHATMAN'S TURKEY PAPER MILLS*, 1794.
Size of the original: 69.3 × 102.0 cm. Image courtesy of the Yale Center for British Art, New Haven (B2002.29).

the neighboring aristocratic estate, Mote Park, seat of Charles Marsham, Lord Romney, MP for Kent and a leading patron of agricultural improvement. Framing the scene is a towering ash tree, a species useful to harvest for farming implements and hop poles but also esteemed for its Saxon heritage as a mote tree and marking a meeting place. Beyond it is a recently harvested hop garden with improbably large pole stacks, a signature feature of the Kentish countryside and the patriotic production of English beer. There is a smooth lawn-like meadow with a group of horses, the leaping white horse the heraldic Saxon symbol of Kent, incorporated in the royal coat of arms to seal the Hanoverian succession (Hasted 1797–1801, 1:64). Kent assumed its strategic geography for a nation at war, as the so-called Garden of England stood in the front line of a threatened French invasion of Britain.

Sandby's finely delineated view sustains an even focus on the horizon, documenting a landscape that is emblematic as well as empirical, with implications far beyond its immediate locality. Such is the attention to detail, the remorseless lucidity of everything, that the picture is less a faithful reproduction than an idealized imitation; it is also a principled defense of topography as a genre as well as a utopian vision of this countryside and its role in the defense of the realm. While the picture draws on a long decorative and documentary tradition of prospect views, and some atlases in its regional conspectus of geographical virtue, it also alludes to the military survey then being conducted in Kent, the first county map of what became the Ordnance Survey, the finished drawings for which were esteemed as works of patriotic pride, "the finest piece of Topography in Europe" (Flint 1883, 144).

It was therefore not only the commercialism of many topographical enterprises that occasioned disagreement of the kind exemplified by Britton's riposte to Fuseli's polemic against "map-work," but also its social nature. With the dramatic expansion of the British art world, especially in the second half of the eighteenth century, and the formulation of a distinctive, influential, and increasingly professionalized establishment, headed by the Royal Academy of Arts, that promoted, at least in theory, a disinterested, civic-minded art as part of a liberal-humanist agenda, it became increasingly necessary to establish some distance from the taint of trade or amateur or utilitarian practice of the kind associated with some of the topographical imagery surveyed there. As with other academic theorists of the period, Fuseli's concern was to cultivate a distinctive and individual artistic sensibility, distinct from the mechanical and learned formulas of amateurs, military and naval men, or the less ambitious among his fellow professionals, in a way that disrupted the long-standing balance of the palette and compass. This has continued to have implications for the historical treatment of this material, in terms of written accounts of art and cartography in the period as well as its collection.

We have emphasized that topographical imagery was neither narrowly documentary nor merely illustrative, but was rather a complex, synoptic form of view-making that involved relations of figures and landscape; forms of spectatorship; historical, pictorial, or poetic allusion; and the conflation of the observed and imagined. The accuracy of such views may be understood as a quality shaped by feeling, memory, and projection as well as eyewitness testimony and measurement. The forms of pictorial practice surveyed here expanded in richness and capacity, taking the form of wide-angled prospects as well as short-focused views, addressing a varied and expansive reach of subjects. Despite the cultural significance of topography at the time and since, the continuing power of Fuseli's polemic, and the academic platform it rests on, is most readily apparent in the historic dispersal of much of such material, especially that in paper form, which has resulted in drawings and prints divided between fine art and topography, art gallery and library, some works classed with maps as objective images of place, others with paintings as subjective expressions of the artist.

STEPHEN DANIELS AND JOHN BONEHILL

SEE ALSO: Art and Design of Maps; Cartouche; Color and Cartography; Education and Cartography; Garden Plan; Heights and Depths, Mapping of: Relief Depiction; Iconography, Ornamentation, and Cartography; Signs, Cartographic

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Lapland and Peru, Expeditions to. The geodetic expeditions to Lapland and Peru sponsored by the Paris Académie royale des sciences in 1735–45 were monumental in the history of physical geography and to an extent unprecedented. Although they were not the first scientific expeditions to remote continents (the great expedition of Jean Richer to Cayenne in 1672–73 preceded and motivated them), they were certainly the first to take on such an extreme financial and logistic challenge for the sake of a single objective, in this case the measurement of the length of the degree as a function of latitude. It was hoped that such measurements at points distant from each other by nearly a quarter of the earth's circumference would settle the question of the planet's nonsphericity and resolve conflicting theories postulating either the elongation (like a lemon) or the flattening (like an orange) for the shape of the earth. Mathematical and philosophical reputations turned on this question: Isaac Newton had predicted the flattened earth whereas the notable French astronomers Jean-Dominique Cassini (I) and Jean Picard favored the elongated form on the basis of their own limited measurements.

Although cartography was not a primary objective of the expeditions, the need to correct maps and marine charts was used as an argument by the promoters in the Académie, and important mapmaking was duly carried out. The cartographic argument may well have been seen in part as insurance against failure of the degree measurements and been based on the fear of the explorers returning altogether empty-handed.

The first party to leave France, in 1735, was the Peru expedition, nominally led by Louis Godin, though in effect by a triumvirate including Charles-Marie de La Condamine and Pierre Bouguer. The journey to the cordillera of Peru (today Ecuador) in the region of Quito was arduous and involved a difficult traverse of the Isthmus of Panama as well as delicate political negotiations with the Spanish authorities in both Madrid and the New World. The outcome of these was a requirement to take along two Spanish "minders"' to discourage any illicit trade and espionage. The two chosen were the mariners Antonio de Ulloa and Jorge Juan, who would prove themselves the equal of the French academicians, both as surveyors and observers of the Andean culture.

Over a year passed before the party was assembled in Quito, ready to begin baseline and triangulation measurements, and by this time, disagreements between the three principals had begun to threaten the expedition's success and the reliability of its data. Unfortunately, such friction would continue for the next nine years of measurements and become even more acute after the eventual return of La Condamine and Bouguer to Paris (Godin remained in Peru and returned to Spain only in 1751 after being dismissed from the Académie for his negligence).

The second expedition to leave, in 1736, was the Lapland expedition, led by Pierre Louis Moreau de Maupertuis, and it seems to have been an afterthought promoted by Maupertuis behind the backs of the Peru party. It headed not strictly to Lapland, and certainly not to the Pole as was sometimes reported, but more modestly to the region immediately north of the Gulf of Bothnia on the Swedish-Finnish border, with a base in the town of Torneå (now Hararanda on the Swedish side). Consequently, the survey would barely cross the Arctic Circle, covering only about one degree, compared to the three degrees eventually measured in Peru. The party was completed by the Swedish astronomer Anders Celsius, mathematician Alexis-Claude Clairaut, and the priest Reginald Outhier, who was an accomplished cartographer and would write the definitive account of the expedition. Also present was the young Anders Hellant, a Finnish student acting as interpreter, but later to become the country's celebrated astronomer.

The dispute concerning the possible polar flattening or extension was to be settled by measurements of the length of a degree of latitude at distances as far apart as possible in one hemisphere. A simple geometrical construction made mathematically explicit by Maupertuis shows that for a flattened earth the degree length increases from equator to poles while for an elongated spheroid it decreases. To complete a measurement of the length of a meridian degree, two kinds of techniques were involved: ground surveys with accurate angular and length measurements to establish a chain of triangulation along the arc of the meridian plus astronomical measurements of star elevations near the zenith at points a known distance apart on or near the meridian. Sun sightings would also be required to fix the meridional direction. Comparison of the elevations of a chosen star, determined at the end points of the arc as near simultaneously as possible, would then yield proportionately the difference of latitude between them.

In both Lapland and Peru, the crucial baselines were laid out and measured using wooden rods that were constantly compared against reference *étalons* (standards) derived from the standard Parisian toise (1.97 m). In fact, the requirements of the two expeditions prompted the Académie des sciences to commission two new standards, since the original toise du Châtelet, an iron bar actually embedded in the staircase of the Grand Châtelet, had deteriorated with time. The new standards, constructed by the instrumentmaker Claude Langlois, became known as the toise du Nord and the toise du Pérou. Although they were intended to remain protected in Paris, the toise du Nord was commandeered by Maupertuis and taken to Lapland, where it was suspected to have been damaged in the course of the expedition. The Peru expedition relied on a secondary standard, among many others that were made and used by mapmakers throughout Europe in the later eighteenth century.

The triangulation baseline for the Lapland expedition was ingeniously unconventional. Maupertuis decided to measure on the frozen surface of the Torneå River in the winter of 1736–37. This could be done speedily because of the nearly level surface but had the disadvantage of requiring work in near twenty-four-hour darkness with no possibility of retracing once the ice had melted. In Peru, two baselines were measured, at the northern and southern extremes of the suite of triangles near the cities of Quito and Cuenca, thus providing a useful cross-

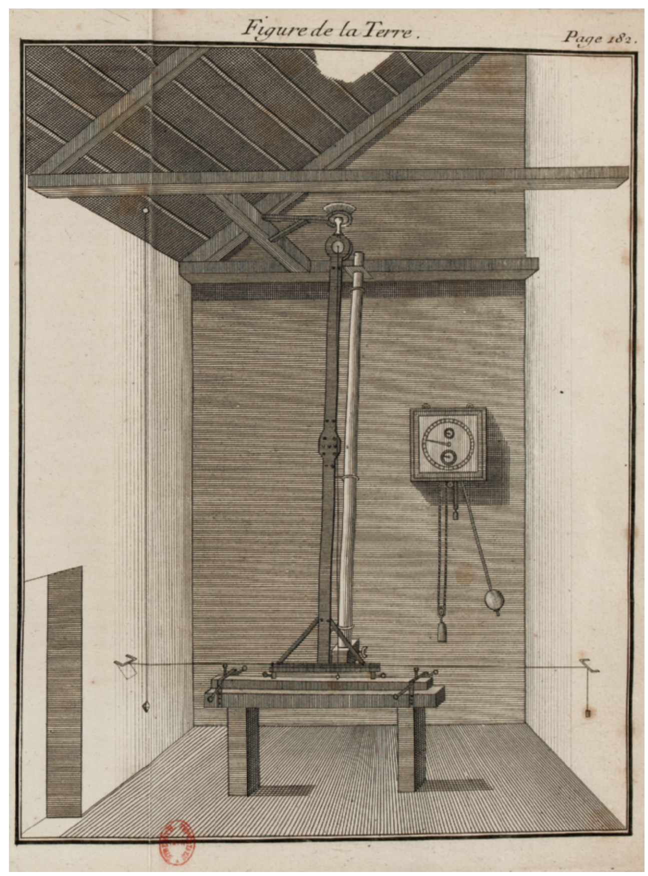

FIG. 435. OBSERVATORY AND SECTOR CONSTRUCTED BY HUGOT, OR THÉODORE HUGO, 1749. From Pierre Bouguer, *La figure de la Terre, déterminée par les observations de messieurs Bouguer, & de La Condamine, de l'Académie royale des sçiences, envoyés par ordre du Roy au Pérou, pour observer aux environs de l'Equateur* (Paris: Charles-Antoine Jombert, 1749), following 182.
Image courtesy of the Bibliothèque nationale de France, Paris.

FIG. 436. *CARTE DU FLEUVE DE TORNEÅ*, 1744. From Réginald Outhier, *Journal d'un voyage au nord, en 1736 & 1737* (Paris: Piget, Durand, 1744), following 96 (fig. 5). See figure 273 for a detail of the baseline and central portion of the geodetic triangulation.
Image courtesy of the Bibliothèque nationale de France, Paris.

check. Angular measurements for the triangulation were carried out using a quadrant while astronomical readings, which could be delayed until surveying of the meridians was complete, required the measurement of only a small angle between the zenith and the chosen star. This could be accomplished using the much-elongated zenith sector (see fig. 396), calibrated over just a few degrees (observation of stars far from the zenith was avoided because of the effect of atmospheric refraction, the atmosphere acting as a lens to give a false position for the star—an effect that vanished in the vertical direction). Quadrants and sectors were theoretically capable of accuracy down to seconds of arc, but were unlikely to achieve this due to the need for dismantling and the rough handling they inevitably received in the field. The design of quadrants had been improved considerably in the later seventeenth century, notably by replacing the original sights (pinnules) with telescopes and crosswires and using micrometer adjustments. The zenith sector used in Lapland was specially commissioned from the London instrumentmaker George Graham and delivered to the expedition site in Torneå. Remarkably, the best sector used in Peru was made on the spot using only local materials (fig. 435) by the expedition's clockmaker, one Hugot, now identified as Théodore Hugo (Ferreiro 2011, 44–45).

The Lapland expedition completed eight triangles leading to a distance of about one degree from Torneå to the town of Kittis almost due north, giving a degree of 57,437.9 toises (fig. 436). The Peru expedition measured just over three degrees from near Quito to a point just south of the city of Cuenca, for 56,753 or 56,749 toises per degree (fig. 437). Thus, the flattening of the earth at the poles was confirmed, the figures corresponding to an equatorial bulge of some twenty kilometers. Both results would be subjected to various corrections, and the Lapland figures were later shown by a Swedish team that checked them in 1801–3 to contain serious systematic errors. A very well-equipped expedition of French military surveyors resurveyed a meridian of over six degrees in Peru from 1900–1906, but due to the loss of sighting points could not pinpoint any errors in the measurements from the 1740s.

This is not the place to detail the various adventures and, in the case of the Peru party, tragedies that befell the expeditions. Maupertuis and party, spending the winter of 1736–37 in Torneå, enjoyed "most of the pleasures

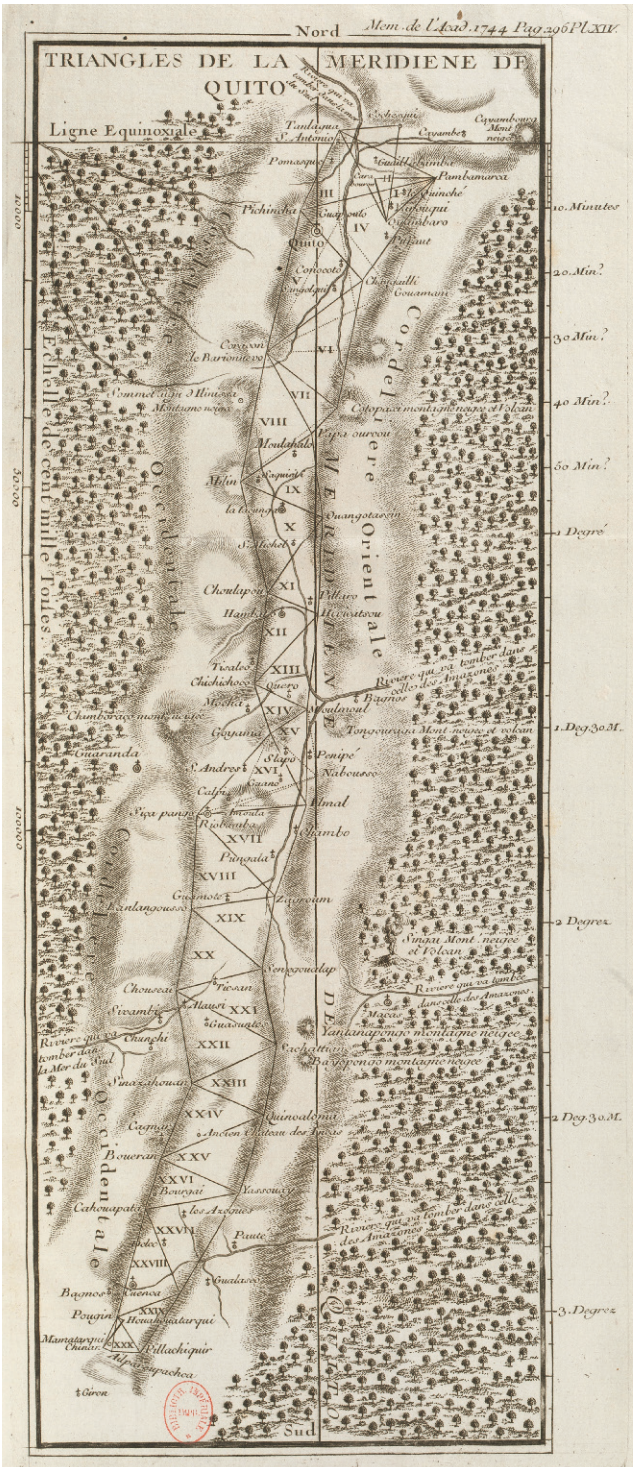

FIG. 437. *TRIANGLES DE LA MERIDIENE DE QUITO,* 1744. From Pierre Bouguer, "Relation abrégée du voyage fait au Pérou," *Mémoires de l'Academie Royale des Sciences, année 1744* (1748): 249–97, following 296 (pl. XIV). Image courtesy of the Bibliothèque nationale de France, Paris.

we are accustomed to in Paris" and caused an ongoing scandal; the Peru expedition lost first the young assistant Jacques Couplet-Viguier to fever in the early days, and then the surgeon Jean Seniergues was murdered by a vengeful mob in the city of Cuenca in 1739 (Hoare 2005, 105, 131, 173–74).

After almost being given up for lost, the Peru party finally arrived back in Paris in some disorder. La Condamine, after his remarkable voyage down the Amazon, reached Paris in February 1745 to find that Bouguer had beaten him by six months, using the overland route via Cartagena. All the return journeys were bedeviled by warfare variously between Britain, France, and Spain, while Admiral George Anson's pillaging of the Peru coast in 1741 had already caused delay in the measurements. The most unlucky was Ulloa, who was captured by the British at Louisburg, brought back as prisoner of war, only to be released when his scientific credentials were discovered. Freed from custody, he was promptly elected to the Royal Society of London before being given safe conduct back to Spain (Whitaker 1966).

There were two remarkable cartographic products associated with the Peruvian expedition. At an early stage, La Condamine became acquainted with the governor of Esmeraldas province, Pedro Vicente Maldonado. Maldonado proved to be a considerable cartographer who had already prepared accurate maps in his part of Peru. He was, it would seem, the first native South American cartographer known to us, and is justly celebrated in Ecuador to this day. He was of great help to the French party, and on the conclusion of the expedition accompanied La Condamine on his epic voyage down the Amazon. Continuing independently to Europe, he brought copies of his maps to the Académie royale des sciences in Paris and the Royal Society of London, where he was nominated as a fellow. But, having survived every possible pathogen in the Amazonas, he died of a fever in London, before he could be elected. The other remarkable by-product was La Condamine's mapping of the Amazon (see fig. 431) with an accuracy that bettered all previous attempts, most notably that of German Jesuit cartographer Samuel Fritz.

The two expeditions generated considerable admiration in literary circles. Voltaire was ecstatic at the success of the Lapland expedition and wrote several poems in praise of the "Argonauts" involved. Later, a superb tribute was paid by George-Louis Leclerc, comte de Buffon, on the occasion of La Condamine's reception into the Académie française in 1761.

MICHAEL RAND HOARE

SEE ALSO: Bouguer, Pierre; Geodesy and the Size and Shape of the Earth; Geodetic Surveying: (1) Enlightenment, (2) France; Instruments, Astronomical; Instruments for Angle Measuring: Theodolite, Graphomètre, and Similar Instruments; La Condamine, Charles-Marie de; Ulloa, Antonio de, and Jorge Juan

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League of Augsburg, War of the. Provoked by Louis XIV's policy of annexation, and beginning with the French sack of the Rhenish Palatinate (spring 1689), the War of the League of Augsburg (1688–97; also called the Ten Years' War, the Nine Years' War, the War of the Palatine Succession, and the War of Orléans) pitted France against the Grand Alliance of Western Europe (the Holy Roman Empire, Spain, England, the Netherlands, and Savoy) led by William III of Orange, *stadhouder* of the Netherlands from 1672 and king of England from 1689. The two most important operational theaters were the Palatinate (1688–90) and the Spanish Netherlands (1690–95). Protected by the fortresses of Sébastien Le Prestre, marquis de Vauban, and strengthened by its unified command and interior lines of communication, France preserved its territorial integrity through considerable military effort. With the Treaty of Ryswick (1697), France kept Strasbourg and Sarrelouis but had to cede Luxembourg to Spain and both Lorraine and Fribourg to their princes. Louis XIV also had to accept the Dutch occupation of the barrier towns in the southern Spanish Netherlands and to recognize William III as king of England.

The late seventeenth century marked an important stage in the French administrative monarchy's evolution. In 1688 the ministre de la Guerre, François-Michel Le Tellier, marquis de Louvois, created the Dépôt de la Guerre to archive at the minister's disposition correspondence from generals and officials in the provinces, including plans of battles, sieges, and encampments. At Louvois's death (1691), Vauban joined engineers from the *département de la Guerre* to those from the *département de la Marine*, creating a corps of *ingénieurs du roi*, which worked on fortified locations and sent their plans, projects, and *mémoires* to the office of fortifications. Thus, as the War of the League of Augsburg began, conditions existed for the conservation of military cartographic production, at least in France.

By its length and the manpower it mobilized, this war obliged the belligerents to transport numerous troops rapidly in order to concentrate them at a given moment on a chosen battlefield. This required understanding different itineraries. Moreover, nourishment and lodging of armies wintering in the field required increasingly detailed knowledge of local resources. Commanders thus felt the need for maps more precise than the small-scale printed maps that gave a synthetic view of operational theaters and more general than the large-scale maps depicting the environs of fortified places produced by the *ingénieurs du roi*. The *maréchaux généraux des logis*, charged with logistics, thus enlisted engineers (who sometimes began as simple draftsmen) to receive commissions as officers attached to an infantry regiment. They rarely signed their maps, which were produced in difficult conditions and sent directly to Versailles. Their cartographic production would have remained obscure if some of them had not gathered and refined their work at the end of the conflict and produced confidential manuscript editions intended for various military figures of high rank. The multivolume "Camps et ordres de marches et de batailles de l'armée du roi en Flandre" by Pennier exists in several exemplars, including one with the Noailles coat of arms in The National Archives of the U.K. (TNA), Kew, another at the Bibliothèque du Museé Condé in Chantilly, three in the Service historique de la Défense at Vincennes, and one at the Bibliothèque nationale de France. Likewise, exemplars of the "Théâtre de la guerre en Flandre" in twenty-one sheets by Jean-Baptiste Naudin (also with the Noailles arms), are held at the Archives nationales de France as well as in the Kriegsarchiv in Vienna and the Hadtörténeti Múzeum és Könyvtár in Budapest (Lemoine-Isabeau and Hélin 1980, 30–31). Adrien-Maurice de Noailles, then comte d'Ayen, probably had these works produced between

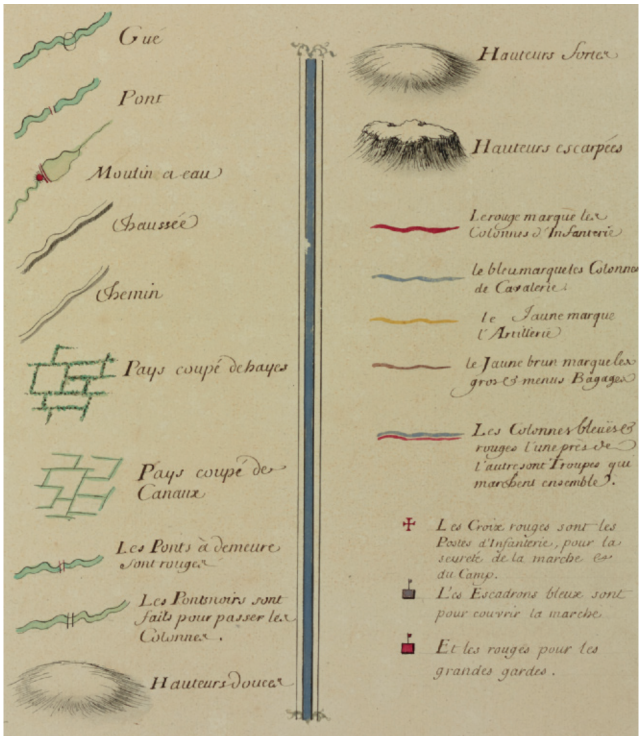

FIG. 438. DETAIL FROM THE KEY FOR THE MAPS OF LE SR. PENNIER, "CAMPS ET ORDRES DE MARCHES DE L'ARMÉE DU ROY EN FLANDRES," 1694. Two columns of signs (not shown) represent man-made and natural features that were common to maps of the period; the two columns shown here comprise signs for features of particular importance to armies on the move: passage across rivers, encumbered fields, bridges that could sustain infantry traffic, heights of three different orders, and a color scheme to distinguish the movement of different branches of the army (infantry, artillery, cavalry).
Image courtesy of the Bibliothèque nationale de France, Paris (Cartes et plans, Ge CC 5061 [7] RÉS).

1696 and 1701 (Lemoine-Isabeau 1984) after his first campaigns in Flanders; he was able to use them during the War of the Austrian Succession (1740–48), in which he was a principal actor.

Uniformly employed conventional signs were added to the plans of battles and camps, to the itineraries of different columns, and to the representation of fortifications in the countryside. The difference between open and fortified cities was distinguished; note was made of burned villages; soil characteristics and observable elements in the countryside, such as mills, isolated trees, or gibbets, as well as roads and river passages, stone or wooden bridges, and fords were all given careful attention (fig. 438). These elements gave a typically military aspect to the maps representing the open field of Flanders, a much-contested site for the confrontation of European powers in the modern period.

Beginning in 1702, military cartographers returned to Flemish and German battlefields, where they participated in all the campaigns in the War of the Spanish Succession. Meanwhile, this martial cartography bound to the land, although confidential, permitted correction of many endlessly recopied cartographic errors, and certain elements quickly became public through printing. Eugène Henry Fricx employed these resources for his *Table des cartes des Pays-Bas et frontières de France* (1704–12), as did Nicolas de Fer in his *Frontières de France et des Païs Bas* (1708–10). Henceforth, the literate public could follow operations on a map.

MARIE-ANNE CORVISIER-DE VILLÈLE

SEE ALSO: Dépôt de la Guerre (Depository of the War Office; France); Engineers and Topographical Surveys; Fricx, Eugène Henry; Military and Topographical Surveys; Military Cartography; Naudin Family

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Level. See Instruments for Distance Measuring: Level

Leveling. See Height Measurement: Leveling

Liesganig, Joseph. Joseph Liesganig was born in Graz in 1719. After joining the Jesuits, he enrolled in the Faculty of Arts of the University of Vienna to study philosophy, rhetoric, and mathematics, but he finally settled on theology. He was ordained in 1748, after which he served as a priest in Komorn (Komárno) and taught mathematics in Kaschau (Košice). In 1752 he returned to Vienna where he was appointed assistant to the director of the Vienna Observatory, becoming prefect of that institution four years later. Subsequently, he was involved in extensive measuring and surveying activities. In 1771, he was appointed dean of the Faculty of Philosophy of the University of Vienna. When many establishments of the Jesuit order in Austria were dissolved, he was given the post of director of constructions in Lemberg (Lviv) and commissioned to produce a map of Galicia and Lodomeria (1772). From 1785, he supervised work on the Josephinische Landesaufnahme in Galicia. His extensive experience with surveying caused Liesganig to believe that the Alps caused deflections of the plumb line. Liesganig invented numerous instruments, including a universal quadrant for leveling, and wrote an essay on latitude measurement (1768). Liesganig died in Lemberg in 1799 (Kretschmer 1986, 448; Zeger 1992, 116).

It was Liesganig who introduced triangulation to Austria. His fellow Jesuit Ruggiero Giuseppe Boscovich, who had conducted a meridian survey of the Vatican State, inspired Liesganig to begin work on a latitude survey in the area of the Vienna meridian in 1759. After joint triangulation work with César-François Cassini (III) de Thury in 1761, which also resulted in a map, *Carte des environs de Wienne* (1763), Empress Maria Theresa officially commissioned Liesganig in 1762 to survey the Vienna meridian across at least two degrees of latitude. After accurately determining two baselines between Neunkirchen and Wiener Neustadt as well as in the Marchfeld plain, he established a triangulation system extending across nearly three degrees of latitude from Sobieschitz near Brünn (Sobešice near Brno) to Varaždin in Croatia (see fig. 263). In 1769, Liesganig also determined two baselines in Hungary. He published the results of his survey work in *Dimensio graduum meridiani Viennensis et Hungarici* (1770). The geographic coordinates determined in these surveys were used in mapmaking for several decades (Dörflinger 2004, 81; Kretschmer 1986).

In 1772, Liesganig was commissioned by Emperor Joseph II to produce an astronomic-trigonometric survey of the recently acquired provinces of Galicia and Lodomeria (part of Poland and Ukraine). After determining three baselines, he oversaw the survey of the entire region by triangulation, resulting in a map compiled for administrative purposes published in 1794. Its highly decorative title cartouche appears in figure 439 (Dörflinger 2004, 115; Wawrik and Zeilinger 1989, 329). In

FIG. 439. DETAIL FROM JOSEPH LIESGANIG, *REGNA GALICIÆ, ET LODOMERIÆ IOSEPHI II. ET M. THERESIÆ* (VIENNA, 1794). Copper engraving on forty-nine sheets; 1:288,000, reduced by Johann von Liechtenstern from Liesganig's original map. This highly decorative title cartouche incorporates allegories of the main rivers of Galicia and Lodomeria and images of the abundance of nature, the inhabitants of the region, surveyors working with the plane table and chains, as well as coat-of-arms. The cartouche was derived from a design by the renowned painter Franz Anton Maulbertsch.

Size of the entire original: 164 × 227 cm; size of detail: ca. 70 × 107 cm. Image courtesy of the Woldan Collection, Österreichische Akademie der Wissenschaften, Vienna (Sammlung Woldan, K-IV: OE/Gal 229, [1-49]).

1824, this map was reedited and published in slightly modified form by the quartermaster general's staff.

PETRA SVATEK

SEE ALSO: Geodetic Surveying: Austrian Monarchy; Society of Jesus (Rome)

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Lomonosov, Mikhail Vasil'yevich. The Russian scientist, writer, and polymath, Mikhail Vasil'yevich Lomonosov, descendant of a fisherman, was born in 1711 in Denisovka (now Lomonosov in his honor), a village on an island in the Severnaya Dvina River. At seventeen he matriculated at the Slavyano-greko-latinskaya akademiya in Moscow and later studied in St. Petersburg at the Akademiya nauk. In 1736 he entered the University of Marburg in Hesse under the tutelage of Christian Wolff, an eminent German Enlightenment philosopher. Lomonosov also studied metallurgy and mining in Freiberg, beginning in 1739.

Upon his return to Russia in 1741, he rose rapidly to distinction at the Akademiya nauk. Lomonosov's scientific exploits are well documented. Less appreciated are his literary and cartographic contributions. Eager to improve Russian education, he joined his patron Ivan Ivanovich Shuvalov in founding Moskovskiy gosudarstvennyy universitet (the state university later named after Lomonosov) in 1755. In 1758, Lomonosov became the head of Geograficheskiy departament of the Akademiya nauk. His chief task was to reinvigorate the collection of geographical information after the end of Peter I's surveys in the 1740s and the closure of the naval academy, Morskaya akademiya, in the 1750s. In a 1757 directive, Lomonosov called for a revision of the 1745 *Atlas Rossiyskoy* based on the collection of new material. To help with the task, the Holy Synod, Svyateyshiy pravitel'stvuyushchiy sinod, supplied fresh descriptions of monasteries and churches, and the senate updated information on villages and their inhabitants (Perevoshchikov 1854, 30–84). Russian districts and provinces returned detailed questionnaires on their natural habitats and economic geographies. By 1766 the Geograficheskiy departament had gathered four volumes of data covering half the country.

Lomonosov's chief contributions were in the area of geographical compilation. He insisted on high empirical standards; he wanted hypothetical material excluded. To make surveyors accountable, he ordered that all the materials used in constructing a map be appended to the map. In a 1763 essay on the origins of the geography department, he argued that mapmakers should have access to census registries so that they could "distinguish villages on the basis of size," and be able to include on maps only the largest villages (1842, 112). In *Novy reglament Akademii nauk* of 1764, he urged a systematic update of maps every twenty years, a prescient idea finally implemented in Russia when the corps of military topographers, Korpus voennykh topografov, first began to update its old surveys in the 1860s.

Despite Lomonosov's ambitions, the actual production in the Geograficheskiy departament during his tenure was modest. Lomonosov made only one map; his manuscript northern circumpolar map, the so-called *tsirkumpolyarnaya karta* in "Kratkoye opisaniye raznykh puteshestviy severnym moryam" (1763), illustrates Lomonosov's belief in the navigability of the polar regions (fig. 440). The map was compiled in two manuscript copies, one of which survives.

Lomonosov also oversaw the restoration of the huge Gottorp globe by a team of German masters in 1747. This globe-planetarium with diameter of 3.1 meters and weight of 3.5 tons was originally constructed for Frederick III, duke of Holstein-Gottorp, and was kept at his castle near Schleswig (Lühning 1997). It was painted inside as a celestial sphere (see fig. 163) and outside as a terrestrial globe. It was provided with a door leading inside and it rotated once per day by means of a water wheel. In 1713, Frederik III presented his ally Peter I with this globe, and in 1717 Peter I placed it near his summer palace at St. Petersburg. In 1726, the globe was transferred to the Kuntskamera and in 1747 it was burned during the great fire. But the description of the globe survived in the Akademiya nauk, which provided the opportunity for Lomonosov to reconstruct it and update its contents.

In March 1765, while continuing his work in the Geograficheskiy departament at St. Petersburg, Lomonosov caught a cold and died the following month.

ALEXEY V. POSTNIKOV

SEE ALSO: Geographical Mapping: Russia

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FIG. 440. FACSIMILE OF MIKHAIL VASIL'YEVICH LOMONOSOV'S 1763 CIRCUMPOLAR MAP BY K. BREYTSHREKHER. Printed as a photo-metallotype reproduction by the Glavnoye Gidrograficheskoye Upravleniye (Central Hydrographic Administration) in 1911.

Image courtesy of the Rossiyskaya natsional'naya biblioteka, St. Petersburg.

nauk i sozdaniye pervogo Akademicheskogo atlasa (1739–1799 gg.)." In *Ocherki istorii geograficheskoy nauki v SSSR*, 47–60. Moscow: Izdatel'stvo "Nauka."

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Longitude and Latitude. In defining and describing the spherical geometry of both the heavens and the earth, longitude and latitude lay at the heart of early modern cosmography. The principles for determining both were laid out in the Renaissance and had been successfully implemented for latitude, but adequate techniques for determining longitude proved maddeningly elusive. For anyone with a degree of cosmographical sensibility—and Europe's educated were steeped in cosmography by means of the didactic "doctrine of the sphere" (Dekker 2002)—the longitude problem was an intellectual itch that cried out to be scratched. A reliable means to determine longitude promised to complete cosmography, to perfect both geographical and marine mapping, and to bring safety to marine navigation. By 1650, government ministers and officials in Britain and France saw the inability to determine longitude at sea as a fundamental impediment to the future development of overseas trade and naval power. They accordingly founded new institutions, each directed to seek solutions, starting with new scientific societies and astronomical observatories: the Académie des sciences (1666) and the Paris Observatory (1671); the Royal Society (1660) in London and the Greenwich Observatory (1675). At the same time, the expansion of public discourse transformed the longitude problem from a research agenda pursued by mathematical practitioners, often seeking social advancement and government reward, into something of a cultural obsession.

The history of the eventual solution to determining longitude at sea, by the use of either chronometers or the method of lunar distances to compare local with standard time, was already laid down in the eighteenth century, for example, in Esprit Pezenas's *Histoire critique de la découverte des longitudes* (1775; see Boistel 2002, 116–18), and it has been repeated and refined ever since. In the twentieth century, historians of cartography have tended to simplify the narrative to emphasize the successful development of the chronometer; the power of this narrative was made apparent when Dava Sobel's *Longitude* (1995), her popular account of John Harrison's invention of the marine chronometer, became a surprise bestseller and then a television miniseries (2000).

Yet there was much more to the matter of longitude, even of latitude, than either narrative can admit. The quest to solve the longitude problem had terrestrial as well as maritime implications, and solutions did not necessarily apply to both (Andrewes 1996b; Dunn and Higgitt 2014). Moreover, navigational practices had developed without the benefit of longitude determination, so that although by the eighteenth century mariners willingly adopted cosmographical solutions for determining latitude, marine navigation remained a pragmatic process that did not actually need directly observed longitudes. Thus, navigational treatises, such as Pierre Bouguer's *Nouveau traité de navigation* (1753) or John Robertson's *The Elements of Navigation* (1754), as well as accounts of the work of state-sponsored and well-educated observers, presented the most refined techniques that were not necessarily followed by all observers (Boistel 1999). It took a long time for each workable solution for longitude to be widely adopted, and alternative solutions continued to be promoted. In the meantime, hydrographers could progressively update their charts with land-based observations so that other mariners could use them in conjunction with the new methods of longitude determination.

This entry therefore first examines the two cosmographical practices that were successfully implemented before 1700: the determination at sea and on land of latitude and then, on land only, of longitude from Jupiter's satellites. It then considers the vexed issue of longitude in relation to sea navigation and land travel; the new forms of publicity, especially in Britain, that led to the offering of prizes and the establishment of the Board of Longitude (1714), which further stimulated the proposal of both workable and impossible solutions; the development and adoption of new instruments and observational techniques that allowed mariners and land travelers to readily determine their longitude; and, finally, the slow and tentative adoption of new techniques. (The calculation of latitude and longitude, whether at sea by dead reckoning or on land through triangulation networks or itineraries, is considered in entries on navigation, geodetic surveying, and geographical mapping.)

DETERMINATION OF LATITUDE Three basic methods were used after 1650 to determine latitude; Joseph-Bernard, marquis de Chabert (1753, 183–85), provides a detailed example of each. Eighteenth-century improvements to techniques, instruments, and tables meant that each underwent significant refinement. Mariners were especially interested in determining latitude because of the oceanic practice of latitude sailing in which ships first sailed due north or south to the latitude of the intended destination and then due east or west to port. Latitude observations were also important on land. Practices thus varied between observers on land and at sea and between surveyors attempting precise determinations or voyagers making observations en route.

The first method, pursued since antiquity, was to measure the altitude (angular height above the horizon) of Polaris; this technique gave rise to the common early modern practice of referring to latitudes as "heights." The altitude of Polaris is not directly equivalent to the observer's latitude, however, because that star is not located precisely at the north celestial pole. The necessary correction factor, which could amount to as much as three degrees, could be approximated from the position of the "guard stars" in Ursa Minor, or measured by a nocturnal (Bennett 1987, 77–79). These imprecisions and the method's further limitations—Polaris cannot be seen properly in low latitudes nor at all in the Southern Hemisphere—led mariners to entirely abandon the method by the 1730s. On land and in the Northern Hemisphere, however, astronomers and careful surveyors continued to observe Polaris, and they used a more precise method to determine the correction factor, by solving the spherical triangle formed by the celestial pole, Polaris, and the guard stars. James Bradley, for example, made this calculation repeatedly in his exhaustive observations to determine the latitude of Greenwich Observatory (published in an article by Nevil Maskelyne in the *Philosophical Transactions of the Royal Society of London* in 1787).

The second solution had first been developed in the fifteenth century to determine latitude when Polaris could not be used and featured the measurement of the sun's altitude at local noon as it transited the meridian. By the 1730s, this had become the standard technique for mariners: latitude is readily calculated with some simple arithmetic using only the sun's declination (celestial latitude), as read from a table, and its observed altitude. But clouds can obscure the sun, and it is difficult to know just when the sun is at its zenith; the latter situation became a problem as mariners adopted ever more precise instruments in conjunction with more precise tables of declination. Furthermore, the creation of watches with regular movements and one-second precision enabled a variant technique known today as "double altitudes and elapsed time": the sun's altitude is measured, at the observer's pleasure, before and after noon, along with the intervening time. Nicholas Facio de Duillier proposed this technique in London in 1716 and, by 1740, Cornelis Douwes was circulating a successful implementation of the technique in manuscript to other mariners in Amsterdam. Douwes's work was translated into English by Richard Harrison in 1759 and then developed by Robertson in the second edition of his *Elements of Navigation* (1764) and others (Taylor 1966, 32, 117–18, 189, 233, 259). Although the method required some complex calculations, especially if the observer was moving, as was likely when at sea, it was increasingly adopted later in the eighteenth century (Tattersall 1987).

The third technique of determining latitude applied the method of observing solar altitudes to measuring the altitudes of known stars. However, the necessary stellar declinations were generally not listed in common mariners' tables, only in the *Connoissance des temps* (from 1690) or *The Nautical Almanac* (from 1767), so this technique seems to have been used only by observers on land. By the end of the eighteenth century, Douwes's method was also being applied to stars.

The determination of latitude was made ever more accurate by several refinements. Mariners had traditionally measured altitudes of the sun and stars with either the back staff or the older cross staff. The increasing adoption, after 1731, of octants and sextants with much greater precision than the back staff required still more precise tables (Bennett 1987, 130–34). New tables were better calibrated to mariners' needs, as when the 1781 edition of Nevil Maskelyne's *Tables Requisite to be Used with the Nautical Ephemeris for Finding the Latitude and Longitude at Sea* included new logarithmic tables that significantly eased the working of double solar altitudes (Tattersall 1987). Furthermore, the finer measurements provided by new instruments were susceptible to subtle errors arising from the refraction of the sun's or of stars' rays through the atmosphere, the dip of the horizon as it curves away and down from the observer, and the magnitude of celestial objects (especially the sun). Careful observers, like Chabert, adjusted for these multiple sources of error. Finally, land-based observers with sufficient time could make multiple observations and average the results. By the end of the eighteenth century, the latitudes of astronomical observatories were being fixed to within 2″; skilled navigators could determine their latitude to 1′.

DETERMINATION OF LONGITUDE FROM JUPITER'S SATELLITES Because the difference in local time between two places equates directly to their longitudinal difference, the latter can be determined by timing the same celestial event from both locations. Such observations had been made of lunar eclipses since antiquity and achieved some regularity in the sixteenth century (Portuondo 2009). However, lunar eclipses were too difficult to measure at sea, and they were too infrequent for routine use even on land. The four moons, or satellites, of Jupiter discovered in 1610 by Galileo Galilei were quickly identified as an appropriate replacement for lunar eclipses (although astronomers continued to observe lunar eclipses whenever they could). First, the eclipses (occultations) of Jupiter's moons as they passed behind (immersion) or emerged from behind (emersion) the planet's body were much more frequent: Io, the first of the four Galilean moons, orbits Jupiter in just 42.5 hours, although planetary alignments and the earth's own rotation mean that observable eclipses occur only once per week, on average. Second, the satellites' motions proved relatively constant, so that the times of future eclipses could be reliably predicted and tabulated; an observer in the field would then be able to compare the local time of an eclipse with that predicted for the same eclipse as seen from an observatory. Galileo himself spent several years in an unsuccessful search for support, first from the Spanish government (1612–30) and then the Dutch (1636–40), to underwrite the work required to bring both telescopes and tables to the necessary degree of perfection (Van Helden 1996, 88–92).

The success of Jean-Dominique Cassini (I) at Bologna in producing a precise ephemeris (published 1668) for the eclipses led Colbert to recruit him in 1669 to head the new Paris Observatory, with the particular charge of developing his tables into a practicable method for determining longitude. Several members of the Académie des sciences undertook voyages to observe Jupiter's satellites elsewhere: on Hven, in 1671–72, observed by Jean Picard; at Cayenne, in 1673, observed by Jean Richer; and then around the coasts of France, by Picard and others, in 1679–81. Back in Paris, their observations were compared to those undertaken simultaneously by Cassini I to determine their longitudes retrospectively; among the results was the now famous 1684 map by Picard and Philippe de La Hire, published in 1693, that contrasted the coastline of France from Nicolas Sanson's 1679 map, with the new, "corrected" coastline (see fig. 625). Cassini I also sent an expedition to Cape Verde, in 1681–82, to test the effectiveness of training nonastronomers in this new method; the success of that expedition led to Cassini I training a group of Jesuit missionaries who left for Thailand and China in 1685 (Hsia 1999).

By 1690, Cassini I had so refined his tables and procedures that the Académie des sciences could begin to publish them in the *Connoissance des temps*. This annual ephemeris contained predictions for the eclipses of all four Galilean moons, although only the predictions for the first (Io) were considered sufficiently accurate to be useful. The ephemeris also included instructions addressed to the nonexpert for using them to find longitude (Van Helden 1996, 93–97, who quotes the instructions given in 1773). By comparison, the efforts of the astronomers at Greenwich were rather haphazard: they produced a variety of tables for the satellites' predicted eclipses, but only intermittently (Van Helden 1996, 97–100). The Paris astronomers continued to refine the tables throughout the remainder of the century, a process helped by the continued refinement of knowledge of the earth's size and shape.

Armed with the *Connoissance des temps* or other tables, an observer could determine longitude on the spot, with respect to Paris. The observer needed only a quadrant to determine local time by observing the sun or stars, a good pendulum clock with which to hold that local time, and a long (up to 15–18 ft; 4.5–5.5 m) telescope with which to observe the eclipse itself. Reports of observations of the eclipses appeared throughout the eighteenth century in the *Philosophical Transactions* of the Royal Society and the *Memoires* of the Académie des sciences, constantly testing the tables against simultaneous observations. However, good determinations of longitude were in practice difficult to achieve.

At sea, the problems of observing the moons of Jupiter onboard ship proved insuperable. Telescopes with sufficient magnification were initially just too long and unwieldy; the magnification necessary to see the moons made the field of view too small to keep focused on the satellite while the ship heaved about. Several attempts were made to stabilize the telescope. Galileo had tried to develop a *celatone*, a special headgear that would stabilize motion, to which a telescope would be fitted (Van Helden 1996, 91).

On land, the process remained cumbersome and the instruments delicate, so it was difficult for travelers and surveyors to use it en route with any degree of accuracy. The large pendulum clocks used to hold the time had to be set up and properly calibrated, so astronomers or surveyors could undertake the necessary observations only when they remained in one location for a period of time. Once the pendulum clocks were set up, observers could time multiple eclipses over a long period and then average the results in order to correct for the unquantifiable errors known to persist in the tables and produce a reliable value. For example, James Horsburgh determined the longitude of the esplanade at Bombay from sixteen observations made over three months in 1803 (Edney 1997, 87–90) (table 2). The still few astronomical observatories in Europe undertook extensive series of observations, both to determine their longitude and to help refine the tables. Simultaneous observations of the times of eclipses, at both the observatory and in the field, were always to be preferred in order to avoid using the ephemerides. The net result was that most terrestrial places, including the ports and headlands important to navigation, remained without a precise check on their longitude. Yet the few fixes made were sufficient, by 1800, to dramatically reshape the small-scale world map well before new marine methods could be widely deployed to resurvey the world's coastlines.

LONGITUDE AND NAVIGATION Although historians have tended to emphasize the quest to determine longitude at sea, and despite the manner in which marine navigation would in the nineteenth century come to rely upon longitude measurement, the utility of longitude for navigation was actually debated throughout the eighteenth century. The need for an easy and accurate method to determine longitude at sea seemed obvious to natural philosophers and mathematical practitioners, who wanted to reform navigation according to cosmographical principles, and to explorers, who wanted to place new lands accurately on the earth's surface; a workable solution would simultaneously allow for much better charts and much safer and more efficient navigation. Yet many active pilots saw longitude as an expensive luxury: it would be useful only so long as it was easy to find, but it was not worth spending time or

TABLE 2. James Horsburgh's observations of Jupiter's satellites to determine the longitude of the Bombay esplanade from Greenwich, 1803 (Edney 1997, 88–89)

		Observed local time of eclipse of one of Jupiter's moons			Corresponding Greenwich time (Delambre's tables)			Time difference			Longitude with respect to Greenwich	
		h	m	s	h	m	s	h	m	s	°	′
Jan	23	14	31	10.5	9	40	2	4	51	8.5	72	47.125
	30	16	24	40	11	33	33	4	51	7	72	46.75
Feb	1	10	52	57	6	1	52	4	51	5	72	46.25
	8	12	46	34	7	55	26	4	51	8	72	47
	11	10	23	35	5	31	48	4	51	47	72	55.75
	18	12	57	26	8	5	34	4	51	52	72	58
	22	16	33	52	11	42	47	4	51	5	72	46.25
	24	11	2	20.5	6	11	16	4	51	4.5	72	46.125
	25	15	31	25	10	39	34	4	51	51	72	57.75
Mar	4	18	5	16	13	13	47	4	51	29	72	52.25
	26	15	20	7	10	26	51	4	53	16	73	19
	28	9	47	39	4	55	22	4	52	17	73	4
Apr	2	7	3	34	2	11	22	4	52	12	73	3
	4	11	41	32	6	49	28	4	52	4	73	1
	13	8	4	1	3	12	9	4	51	52	72	58
	27	11	52	35	7	0	45	4	51	50	72	57.5
									maximum		73°19′	
									minimum		72°46′7″	
									range		32′42″	
									mean		**72°57′14″**	

money on, especially since the usual practice of latitude sailing mitigated any problems that occurred from longitude errors (Chapuis 1999, 46–50). However, the debate is historiographically lopsided, given that most mariners did not publish their arguments, and we are left to infer their position from the record of their actual practices.

Reformers argued that knowing the longitude would have two major benefits: it would help mariners know how close to land they were, and it would help them plot better courses. Without correct knowledge both of his own longitude and that of his destination, the mariner could not know how close he was to land, and he risked shipwreck by coming across land unexpectedly. The potential for disaster was only exacerbated by storms, which limited both visibility and maneuverability. Accounts of such disasters abound, most famously when much of Sir Cloudesley Shovell's fleet ran aground in the Scilly Islands in 1707, killing some 800 people and prompting investigations and recriminations, most of which focused on the weather and his lack of due care (Andrewes 1996a, 207). Knowledge of the longitude would not have actually helped Shovell's fleet. After all, the general problem was with mariners being driven onto land by high winds in a storm or misjudging the entrance to a harbor; even in the early nineteenth century, the ability to find longitude at sea did not noticeably reduce shipwrecks. Nonetheless, reformers later used Shovell's wreck to dramatize the need for a longitude prize. Longitude, they argued, was especially important when close to land, not in the open sea, and indeed the British longitude prize would specify that the greatest danger lay within eighty miles of land. Implicit in this argument was that a solution to longitude would lead to the necessary resurveying of the world's coastlines and the perfection of marine charts and geographical maps.

The danger of running unexpectedly into land was widely acknowledged. What was disputed was the preferred solution. Navigators themselves generally suggested keeping a good watch; moreover, they often systematically overestimated the distances traveled, so as not to reach land unaware, and made sure that they were at the correct latitude for their destination well before they expected to sight land. Such pragmatic solutions sufficed for most journeys. Some routes, however, were particularly dangerous. Cape Horn's winds and currents made the calculation of a ship's position notoriously difficult, as attested by the famous near wreck of George Anson's flotilla in 1741. The steady expansion of trade with the East Indies led to the development of new shipping routes that were much more dependent on knowing longitude: the hazards included barely visible reefs, and the standard routes called for course changes in the middle of the ocean rather than within sight of an island. Travel in the South Atlantic, for example, required correctly setting up course changes out of sight of land to round the Cape of Good Hope. And once round that cape, British ships headed for China would be expected to travel out of sight of land almost to Australia before turning northward at the correct point, all without a visible sign. While the point could be determined by dead reckoning, the ability to determine longitude easily would be useful in such circumstances to identify exactly when to shift course (Cook 1985, 189; 2006, 76).

Furthermore, reformers hoped that if navigators could find longitude at sea, then they could plot efficient courses. They could abandon the inefficiencies of latitude sailing and instead sail direct courses along great circles. The resultant shorter voyages would reduce the likelihood both of navigational catastrophe and of outbreaks of typhus and scurvy (Ashley 2001). Knowledge of longitude would also allow a ship to take a less predictable course in order to avoid pirates or other enemies who would lie in wait along the principal sea routes. Moreover, it would mean that mariners would never again be lost at sea. In the case of Anson's ill-fated voyage, after rounding Cape Horn he spent eleven days searching for the island of Juan Fernandez. Initially judging that they were already west of the island, they ran east for several days, only discovering their mistake on sighting the inhospitable coast of the mainland; retracing their path consumed over a week, while dozens of men died of scurvy. The problem lay partly in Anson's inability to find longitude and partly in the erroneous information they had about island's actual longitude. A reliable method of finding longitude, and its use in resurveying the world's coasts, would eventually eliminate both sources of error.

But cases like Anson's were rare. In practice, most ships followed well-defined routes, and the routes were determined by patterns of wind and currents, the needs of convoys, and experience (Cook 2006, 78). Setting out for untried routes was widely seen as too risky for all but a few dedicated, state-sponsored mariners such as James Cook and Jean-François de Lapérouse (whose expedition famously disappeared in the southern Pacific in 1788). Indeed, the major marine surveying expeditions of the eighteenth century were actually enabled by the new techniques for determining longitude. In short, the ability to determine longitude at sea would be extremely useful for exploration and surveying and for naval vessels needing to depart from the usual shipping lanes, but it promised little immediate advantage for day-to-day navigation.

The result was a marked divide. On the one hand, a passionate coterie of cosmographers and geographers, who had the ear of courtiers and politicians, worked with an excited public to push for state sponsorship of the solution to the determination of longitude at sea—whether directly through the establishment of the royal observatories or indirectly through various prizes—in order to promote the state's interests in marine trade and naval power. Finding longitude offered substantial benefits for cartography, for boundary determination, and perhaps for diplomacy. It offered a chance to show the utility of science, to strike it rich, and to win an international competition. And while it was not necessarily the most cost-effective way of improving navigation, it promised eventual benefits for practical navigation as well. On the other hand, the skepticism of navigators showed in the slow acceptance of the new techniques and instruments when they were successfully developed. Despite great efforts from states and the companies, it took a generation or more for the new methods to be widely adopted.

Publicity: Prizes, Crazes, and Institutions

Interest in solving the longitude problem was stimulated in part by formal prizes and in part by the expectation that a method for finding longitude would earn the author a generous pension. Spain was at the forefront in offering rewards, and, as a result, in the sixteenth and seventeenth centuries almost every major cosmographer working in Spain's dominions put forward some form of longitude proposal; many of the proposals survive in the archives of the Casa de la Contratación in Seville, and several were tried at sea but none achieved notable success. The Dutch also encouraged work on a solution. It is not surprising that Galileo would look to both states in order to monetize his plans to find longitude by using Jupiter's satellites (Howse 1980, 10–13; Turner 1996, 117–18).

After 1650, state support of research into the longitude problem would feed, and be reciprocally fed by, the desire of a newly emergent "public" to pronounce on matters of state policy and cultural practice. The expansion of the public marketplace for specialized information is evident from Christiaan Huygens's books explaining the pendulum clocks he designed for shipboard use: whereas he addressed and distributed both his *Horologivm* (1658) and his *Horologivm oscillatorivm* (1673) to small scientific and political elites, to establish the priority of his ideas and to encourage their financial support of his work, he substantially expanded the later work in order to appeal to a more indeterminate public, or at least to those who were interested in horology and cosmography and could afford such an expensive work (Howard 2008).

The interplay of politics, science, and public pressure was most pronounced in Britain. In 1657, Henry Bond had resurrected the idea that variations in the earth's magnetic field could be used to determine longitude, and the idea was very quickly picked up by the Royal Society after its founding in 1660. The Society's interest in an astronomical solution and in Huygens's clocks prompted a broader public expression of interest, in what might be called the first longitude craze. Bond's continued proselytizing for a magnetic solution and his 1673 dedication of tables of both declination and inclination to Charles II led the king to form an official committee to assess his claims in conjunction with another committee established in response to a private appeal by an otherwise unknown Frenchman, the Sieur de St. Pierre, who pushed for the method of lunar distances. The result of these committees was the creation of the Greenwich Observatory in 1675, specifically to undertake the work necessary to implement the lunar method (Forbes 1975, 15–16, 18–24; Howse 1980, 24–30; Bennett 1985). The observatory's formation stimulated yet more pamphlets written by projectors who claimed to have solved the longitude problem to the point that they were satirized in 1688 by an anonymous author who suggested that Digby's sympathy powder could be harnessed to cause a dog to bark at preselected times, establishing simultaneity, and therefore a method for measuring time differences (Ashley 2001, 155–72).

This round of public fervor led Thomas Axe to provide in his will for £1,000 to reward the development of a method whereby men "of mean capacity" could find longitude at sea to within half a degree. Although Axe seems to have been convinced that the problem of longitude was all but solved, no claims were ever paid out after his death in 1691, perhaps because the terms of the will required affidavits from twenty shipmasters who had used the method at sea (Turner 1996, 120–23, 129). England was not alone in such projects; in France, in early 1714, the Parliamentary counsel Rouillé de Meslay endowed a prize to be awarded by the Académie des sciences. He died in 1716, and thereafter the Académie set occasional questions for the prize related to finding longitude; the prize offered, however, was not large, generally 2,000 livres (or about £100), and was more often on adjacent subjects (such as questions of celestial mechanics) rather than on longitude per se. In the 1760s and 1770s several questions were set on the best way of finding time at sea, but there was difficulty in establishing adequate testing at sea, and the Académie wound up adjudicating between the chronometers of Ferdinand Berthoud and Pierre Le Roy (below) rather than establishing new lines of research (Chapin 1990, 90–91, 103–6).

In Britain, the public fervor was seized upon by projectors, culminating in the institution of a longitude prize. Motivated by the disaster of Shovell's 1707 shipwreck, William Whiston and Humphrey Ditton developed a completely new solution to the longitude. They proposed to anchor a network of hulks at fixed points throughout the ocean, or at least near the major shipping lanes; at a specified time, each crew would set off a firework, precalibrated to explode at 6,440 feet; ships could then use the timing and location of these fireworks to fix their position relative to the nearest hulk. The practical difficulties of such a method were daunting and, although Whiston would subsequently spend many years to develop fireworks and a sea anchor to fix the ships in place, no one seriously sought to implement their ideas. But Whiston and Ditton were successful in their agitation for the establishment of a state-sponsored prize, which they expected to win. They petitioned parliament in 1714, emphasizing the need to extend Britain's naval capabilities. The committee appointed to review the petition called on several astronomers and concluded that while none of the methods yet proposed was likely to be workable, an open and substantial prize would still be worthwhile (Howse 1980, 48–49; Gingerich 1996, 142–44).

The resultant Longitude Act (1714) featured truly substantial prizes: £10,000 to reward the finding of longitude to within one degree, £15,000 to within 40′, and the full reward of £20,000 to within 30′. Further, interim awards could also be made to encourage research. Proposals were to be evaluated and awards made by a group of commissioners, including the first lord of the Admiralty, the speaker of the House of Commons, the president of the Royal Society, the astronomer royal, and the Lucasian, Plumian, and Savilian professors at Cambridge and Oxford, who would come to be known collectively as the Board of Longitude. Half of an award was to be given when the Board was convinced that a method was workable "within Eighty Geographical Miles of the shores, which are the Places of greatest Danger"; the other half was to be given only after a sea trial (Howse 1980, 50–53; Stewart 1992, 186–92; Schiavon 2012). The Board came to interpret the act's ambiguous requirement that a method be "Practicable and Useful at Sea," as meaning that the prize was intended to *replace* the monopoly that would otherwise be expected from such an achievement. The Board would accordingly rule that a technique was not truly practicable as a solution if only one person or workshop could successfully produce it. Rather, to gain the prize, an inventor had to publish the method and train his competitors. (The French regent in 1716 also offered a large prize of 100,000 livres, but it was never awarded and the money may never have been made available; Chapin 1990, 118n30.)

The most immediate effect of the huge prizes offered by the 1714 Act was to turn Britain "longitude mad," as Dr. James Lind would put it in 1765 when the first large award to Harrison reawoke public interest (Taylor 1966, 58). No fewer than twenty-six pamphlets on the longitude problem were published in London between 1714 and 1726 (Turner 1996, 131–32) and were widely advertised in the daily and weekly press (Wigelsworth 2008). Most of these early suggestions were simply recodifications of well-known principles, their authors hoping that they could reap some of the expected reward. For example, several explained that longitude could be found with a sufficiently accurate clock, but omitted discussion of how to build it, or by the motions of the moon, once someone else had determined its motion and had calculated the necessary tables. Other works offered ways of simplifying calculations, improving dead reckoning, and measuring distances, though they rarely went beyond what could commonly be found in navigation textbooks. Would-be recipients of the prize also directly petitioned members of the Board and others, notably Isaac Newton, sought to circumvent the Board's open policy and so secure a monopoly patent from the Crown. While most proposals were simply naïve restatements of established cosmography, some were bizarre. For example, Isaac Hawkins suggested the use of a barometer to find the local high tide even while at sea, which he thought would give the position of the moon and so the longitude, while another method suggested that the difference between time told from the sun and time told from the stars would give longitude (Stewart 1992, 192–202; Gingerich 1996).

Most of these proposals vanished immediately into obscurity, despite complaints of collusion and bias by their authors. But they were also the subject of public ridicule. Much of this was political in nature. Tory and High Anglican commentators were opposed to natural philosophers generally for their materialistic leanings and their skeptical dismissal of dogma, and to Whiston in particular for his denial of the Trinity. Thus, John Arbuthnot complained that Whiston's proposal had spoiled his own intended satire that, because there was "no pole for East & west," the European states should join together to "build two prodigious poles upon high mountains with a vast Light house to serve for a pole Star" (Stewart 1992, esp. 192; Olson 1983, 179). Arbuthnot's collaborator, Jonathan Swift, in the third of his *Drapier's Letters* (1724), compared finding the longitude to the equally impossible philosopher's stone or perpetual motion; more generally, Swift argued that the

FIG. 441. DETAIL OF THE "LONGITUDE MADMAN." From the first state of William Hogarth's print of scene eight (in Bedlam, London's insane asylum) of his "Rake's Progress" (London, 1735), showing the "longitude madman" and his attempted solution, complete with William Whiston's exploding mortars. Etching and engraving on paper.
Size of the entire original: 34.6 × 38.7 cm; size of detail: ca. 14.5 × 11.0 cm. Dallas Museum of Art, Texas, USA/Foundation for the Arts, the Alfred and Juanita Bromberg Collection, bequest of Juanita K. Bromberg/Bridgeman Images.

pursuit of natural philosophy led to madness and the same radical enthusiasms that lead to revolutions (Olson 1983, 186–87). But criticism of the popular craze for longitude was not necessarily politically motivated. Most famously, when the Whig-leaning William Hogarth depicted the lunatic asylum of Bedlam in the last painting of his "Rake's Progress" series (1733), he included a madman obsessively trying to solve the longitude problem (fig. 441); the diagrams he drew on the wall include a Whiston- and Ditton-style mortar firing off high-flying ordnance (Kuhn 1984, 50–52).

Even so, the huge prizes of the 1714 Act did encourage more practical solutions. The Board of Longitude did not actually meet or allocate money until 1737, when John Harrison's work on a marine chronometer had started to promise an eventual solution. Thereafter, until 1765, almost all of the Board's awards went either to John Harrison directly, to help fund his researches, or to fund trials of his chronometers; the remainder went to testing Nevil Maskelyne's competing technology of lunar distances. In the process, the problem of longitude became less of a public obsession. Hogarth recognized this profound change of cultural status when, in 1763, he altered the engraved version of his Bedlam scene: he largely obliterated the longitude madman's mural by adding a large halfpenny on which appeared a wind-blown Britannia, perhaps as a statement of the poor state of the nation.

By 1765 the Board had exhausted its funds and needed to return to Parliament both for operating funds and, now that sea trials had been successfully accomplished, for awards to be made to Harrison (£10,000) and to Tobias Mayer's widow for his work on lunar tables (£3,000) (Barrett 2011). These awards led to suspicions of a direct conflict between the two leading methods for finding longitude at sea and to accusations that the astronomers on the Board were biased against Harrison and his chronometers. The ensuing controversy lasted for years, until Harrison directly petitioned the king, resulting in a further payment of £8,750 by a special act of Parliament in 1774. The Board continued to give smaller awards, most notably for improvements in chronometers, and it also funded a variety of expeditions, both to test the various methods and to observe the longitudes (using Jupiter's satellites) of the various places used in the trials in England and in the Caribbean. It also paid for instruments and salaries to send astronomers along on voyages, with instructions to test various possible methods, and it was involved in James Cook's second and third voyages (1772–80), Constantine John Phipps's arctic voyage (1773), George Vancouver's voyage to the Pacific Northwest (1791–95), and Matthew Flinders's survey of Australia in 1801–5, among others. In 1818, a further act gave the Board responsibility for finding a Northwest Passage. Ultimately, the Board was dissolved by Act of Parliament on 15 July 1828, declared to be no longer useful, and the prize officially ended. The Board had spent a total of £157,000 between 1714 and 1828: 33 percent on rewards, a little less on publications, 15 percent on expeditions for trials, and the remainder on other expenses such as paying a secretary and reimbursing travel expenses for members (Howse 1998).

DETERMINATION OF LONGITUDE BY MAGNETIC VARIATION A potential nonastronomical solution to determining longitude at sea was developed as a spin-off from attempts to model terrestrial magnetism. If the spatial pattern of variation in the earth's magnetic field could be defined, observations in the field of magnetic variation and one global coordinate, latitude, should permit the discovery of the other coordinate, longitude. Magnetic variation itself was readily observable in the form of declination, the difference between magnetic and geographic north. As instruments became more sensitive in the eighteenth century, it also became possible to measure inclination, i.e., the dip of the magnetic field. Latitude was, of course, also readily observable. Longitude could therefore be determined; only a sufficiently good model of terrestrial magnetism was lacking.

Natural philosophers had proposed models of terrestrial magnetism throughout the early modern era. In the 1590s, for example, Petrus Plancius had argued that declination was zero along four meridians—the first through the Azores (his 0° meridian), and three others—between which declination varied in a consistent, if complex, manner. Plancius created a special device to solve the spherical trigonometry necessary to determine longitude, which was field-tested by the Verenigde Oost-Indische Compagnie (VOC) in 1595. But grounded as they were in minimal observations, such models proved inadequate to the task and were abandoned early in the 1600s (Davids 1990, 281–85; Jonkers 2003, 56–61). The concept of using magnetism to determine longitude resurfaced with Henry Bond's 1673 tables; when his proposal was rejected, Bond further specified the use of only magnetic inclination in his pretentiously titled *The Longitude Found* (1676); but, as Peter Blackborrow replied, in his *The Longitude Not Found* (1678), Bond's model was grounded in too few observations to have any merit (Jonkers 2003, 88–89).

One of Edmond Halley's goals for his voyages to the South Atlantic in 1698–1701 was to make extensive and careful observations in order to perfect the model of terrestrial magnetism and so improve knowledge of the longitude. Combining his data with observations culled from the logs of ships in the East India trade, he made two maps in which he depicted the spatial pattern of magnetic variation by means of lines of constant declination (isogones). His map of the Atlantic was first published probably in 1701 (see fig. 348), that of most of the world in 1702; lack of data meant that he left the Pacific blank in the latter. Halley thought his Atlantic map sufficiently detailed to aid mariners in approximating their longitude. The map was published by the marine book and chart sellers Mount and Page and was accompanied by a brief explanation that was intended to be added to its sides; indeed, in this form, the map would be reprinted throughout the century in *The English Pilot, the Fourth Book* (fig. 442). As Halley explained in this extra text, the mariner could use the chart to "estimate" the longitude: where the isogones ran north-south and close together, as near the Cape of Good Hope, they would permit mariners to gauge their longitudinal distance from land; Halley admitted, however, that between Europe and the West Indies, the isogones ran predominantly east-west and so did not change sufficiently quickly to provide a check on dead reckoning. Finally, Halley noted that the pattern of isogones would inevitably shift as the earth's magnetism varied, and Mount and Page would indeed alter the isogones in later editions of the map (Thrower 1981, 29–66, 365–70).

It has been argued that Halley first defined the curve of each isogone as a complex polynomial equation (Murray and Bellhouse 2017). Even if Halley laboriously did so, rather than simply interpolating the curves by eye, there can be little expectation that the map's later, less mathematically competent editors followed the same process. The supposition that Halley used his own model of global magnetism to extend the isogones on his maps beyond his data points does seem likely.

Halley was not the last natural philosopher to collect information on magnetism or to try to model and map the earth's magnetic field (Chapuis 1999, 58–62; Radelet-de Grave 2002; Jonkers 2003; Howarth 2003). Observations were frequently published by both the Académie des sciences and the VOC and were increasingly represented cartographically as well. New observations by James Dodson and William Mountaine led to new world and Atlantic maps in 1744 and 1758, with Dutch copies also being published. Moreover, in the 1741 and 1768 revisions made to the VOC's sailing directions, the company's navigators were encouraged to use the charts of magnetic declination as a check on dead reckoning at designated points and so as an aid to determining when it was time to change course, much as they might use other local signs such as seaweed or birds. Evidence of the method continued to appear in ships' journals until the late 1780s, when the VOC adopted the method of lunar distances (Davids 1990, 285–90). Thus, despite early arguments that measurements of magnetic declination, or inclination, might be combined with observations of latitude to determine longitude precisely, eighteenth-century charts of terrestrial magnetism were used only as another check on the calculation of ships' positions, and only so long as adequate techniques for determining longitude were not available. In

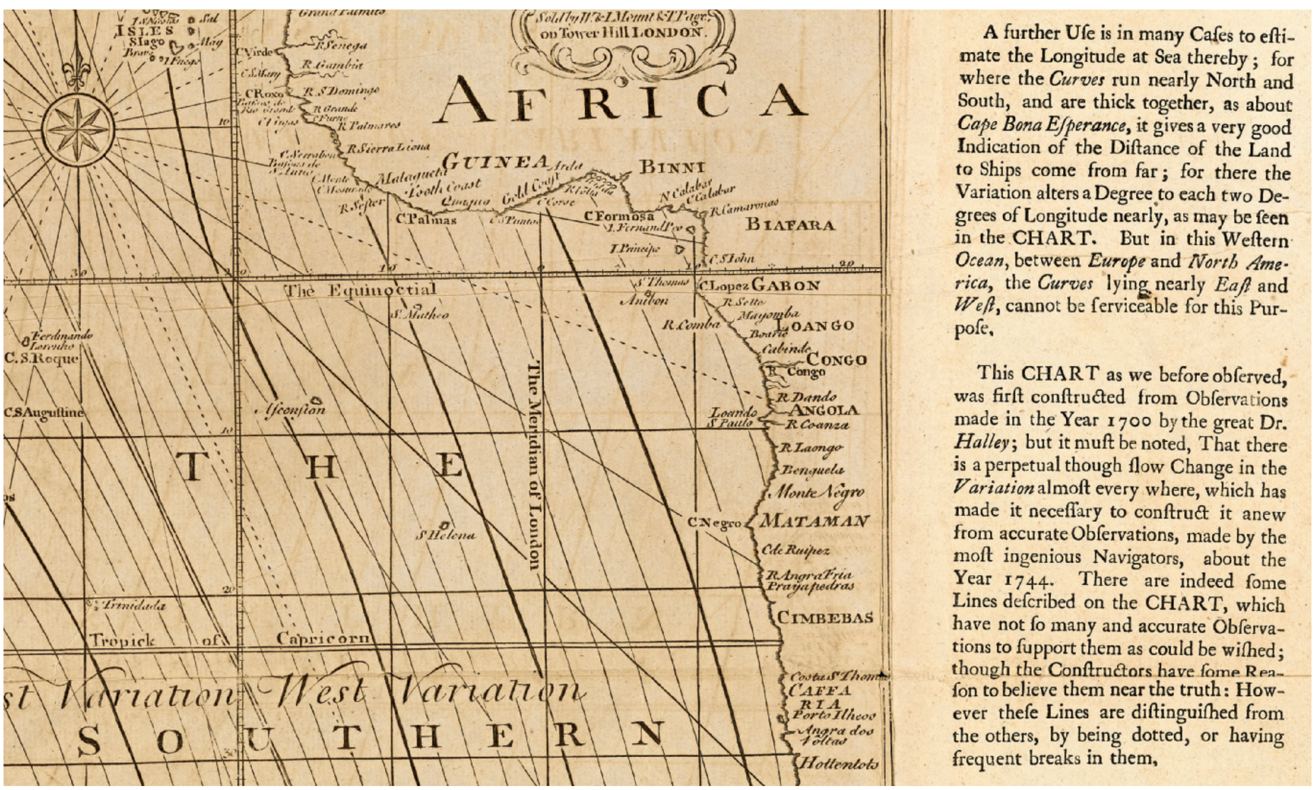

FIG. 442. DETAIL FROM A LATE VARIANT OF EDMOND HALLEY'S 1701 ISOGONIC MAP OF THE ATLANTIC. From *The English Pilot, the Fourth Book* (London: Mount and Page, 1773), showing part of the map and the attached letterpress panels explaining the map and its potential use in determining longitude. This explanation noted that the isogones had been updated after further magnetic observations by James Dodson and William Mountaine, published in 1744. Size of the entire original: ca. 58 × 71 cm; size of detail: ca. 20.0 × 33.5 cm. Image courtesy of the Osher Map Library and Smith Center for Cartographic Education at the University of Southern Maine, Portland (OS-1773-4).

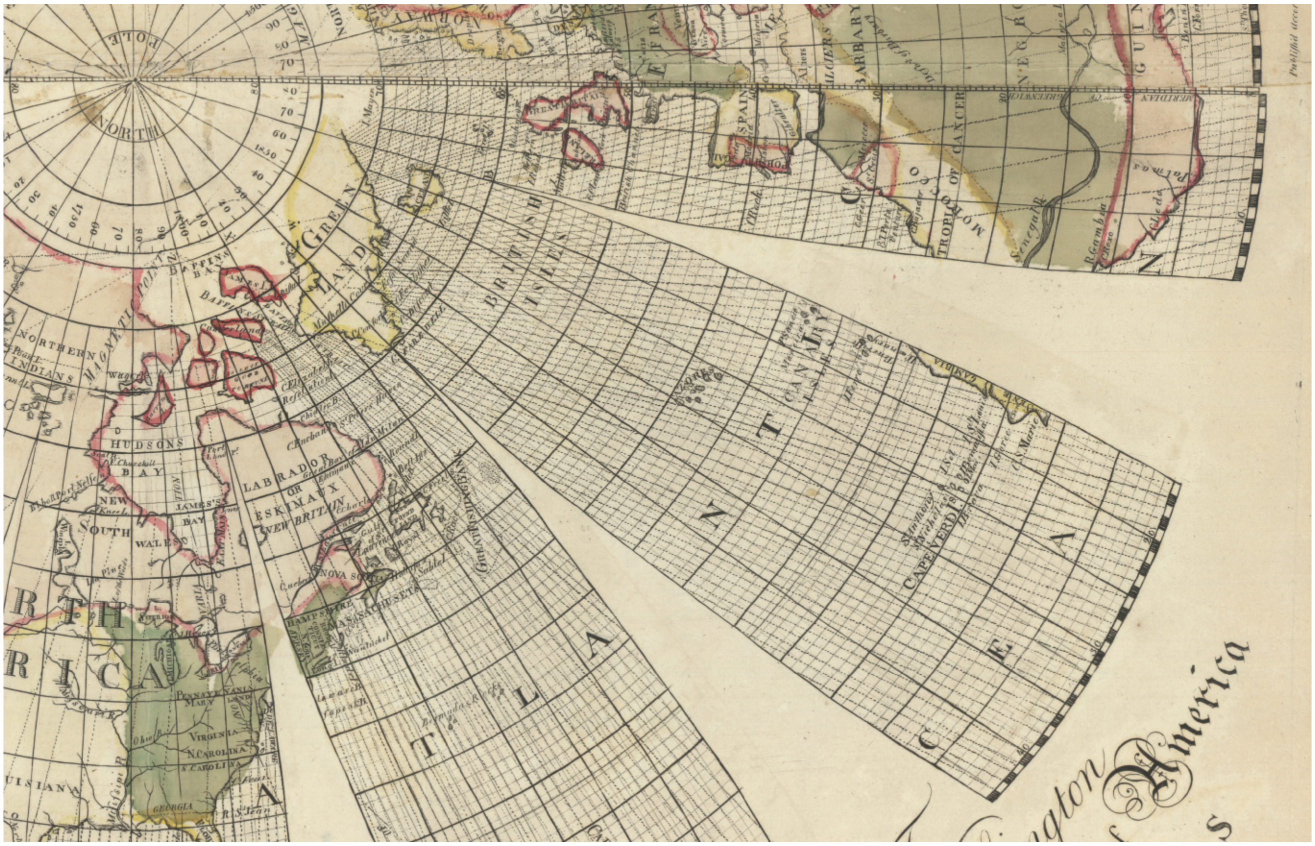

FIG. 443. DETAIL OF THE NORTH ATLANTIC OCEAN FROM JOHN CHURCHMAN'S MAP OF MAGNETIC VARIATION IN THE NORTHERN HEMISPHERE. From his *An Explanation of the Magnetic Atlas* (Philadelphia: Printed by James & Johnson, 1790). Note the novel projection of the hemisphere in a series of interrupted gores.

Size of the entire original: 75 × 66 cm; size of detail: ca. 22 × 34 cm. By permission of the Pusey Map Library, Harvard University, Cambridge (QC814 .C55).

this respect, the arguments by the American land surveyor John Churchman, that the detailed maps of both declination and inclination in his *An Explanation of the Magnetic Atlas*, published in four editions on both sides of the Atlantic between 1790 and 1804 (fig. 443), could be used to find longitude stand as quite anachronistic (Jonkers 2003, 121–27).

DETERMINATION OF LONGITUDE BY LUNAR DISTANCES Johann Werner is generally credited with explaining in 1514 how to find terrestrial longitude by using the moon's motion against the fixed stars: if the moon's motion is known sufficiently well, its predicted movement could be recorded in an ephemeris. The traveler, at sea or on land, would need to measure only the angular separation—or lunar distance—between the moon and the sun or a known star, without needing to wait for an eclipse. Tables would indicate the time at the observatory when the celestial object would be at the same distance from the moon. A comparison of observatory and local time would thus provide the longitude (Howse 1996).

Although the idea was simple enough, the practical problems were daunting. Even so, it had great conceptual appeal as a strictly astronomical procedure, and it continued to be developed, most notably by Jean-Baptiste Morin. As already noted, the Greenwich Observatory was founded in 1675 specifically to conduct the work necessary to implement the method. The first part of this project required the precise definition of the locations of the fixed stars and was accomplished in large part by the first astronomer royal, John Flamsteed, with his star catalog, posthumously published in 1725.

The second part of the project was the definition of the moon's motion. It proved especially challenging to attain the necessary precision. To achieve a result to the nearest half-degree of longitude required that a combined error from the tables and field observations amount to no more than just one minute of arc. Part of the problem was solved by the steady improvement of instrumentation, and in particular by John Hadley's development of a new reflecting quadrant. When tested at sea in 1732, it was found to be accurate to better than one minute of arc; thereafter, the quality of observing instruments continued to increase as the optics and the division of the graduated circles were steadily improved.

The key problem remained a model of lunar motion. Understanding the moon's motion was significantly aided by the 1687 publication of Newton's theory of gravity, and Newton himself developed a theory to explain its motion in 1702 (Kollerstrom 2000). Halley, Flamsteed's successor in Greenwich, set out to refine the lunar tables, but his observational skills were compromised by his age (he was sixty-six when, in 1722, he began an eighteen-year course of lunar observations). Bradley, appointed in 1742 as Halley's successor at Greenwich, continued to make lunar observations that would eventually contribute to the solution. Furthermore, prizes offered in 1750 and 1752 by the Russian Akademiya nauk in Saint Petersburg, couched in terms to test Newton's theories by considering lunar motion, stimulated several continental scholars to refocus attention on modeling lunar motion, but most were unable to overcome limited observations to achieve precision greater than three or five minutes of arc. Nonetheless, naval officer Jean-Baptiste-Nicolas-Denis d'Après de Mannevillette and astronomer Nicolas-Louis de La Caille tested some imprecise tables of lunar distances on their voyage to the Cape of Good Hope in 1753–54, and in 1759 Le Caille published his methods and the associated tables in the *Connoissance des temps* for 1761. The necessary corrections for the theoretical models eventually came from the observational work of Mayer (Wepster 2010). Mayer sent his tables to London in 1755, and they were successfully tested at sea in 1761–62 by Nevil Maskelyne. Mayer completed still more accurate tables, which were tested first by Carsten Niebuhr in 1761 (Baack 2013), and then again by Maskelyne on his 1763–64 voyage to Barbados, when he also tested Harrison's fourth chronometer. Maskelyne's success with Mayer's second tables, and with La Caille's computational methods, led to the formal adoption of lunar distances by the Board of Longitude in 1765, which began to publish them in *The Nautical Almanac* in 1767; Mayer's widow was awarded £3,000 by the Board for his share of the grand prize (Forbes 1975, 120–25; Sadler 1976; Howse 1980, 60–67; Boistel 2010, 151–53).

Yet the process of using lunar distances in the field was complex. A pair of observers first needed to observe, almost simultaneously, the altitude of the moon, the altitude of the sun or a known star, and the lunar distance between the moon and the sun or star, all observations being timed and repeated several times to permit the means of all measured angles and times to be calculated. The altitude of the sun or star would give local time, by calculation. Once corrected for refraction and parallax, and reduced to the center of the moon and sun (if used), the lunar distance could be compared with the tables to define the apparent time at the observatory; comparison of this apparent time to the observers' local time gave the difference in longitude. The many calculations took Maskelyne, on his field trials, up to four hours (Howse 1996, 155–58, gives a worked example).

As astronomer royal after 1765, Maskelyne sought to simplify the method of lunar distances by precalculating as much of the problem as possible, thereby creating specialized tables rather than letting mariners struggle with general-purpose tables. The tables in *The Nautical Almanac* were progressively modified; after a couple of decades, careful table design and the provision of preprinted forms reduced the necessary calculations to about thirty minutes, rendering the method much more practical. Maskelyne hired several full-time computers, and over time they managed to increase the speed of production of new tables until the almanacs were routinely printed five years in advance and made available in multiple ports (Croarken 2003).

The popularity of lunar distances was aided by the publication of preprinted forms outlining the complex steps (Howse 1996, 157), first produced in 1768 by Robert Bishop and in 1771 by Jean-Charles Borda, and by efforts to educate mariners (Boistel 2010, 153–57). The Board of Longitude set up a certificate system in 1769, which trained only fourteen people in the first two years; thereafter the Board bowed to complaints from experienced navigators and focused its efforts on training beginners (Schiavon 2012). By the 1790s, use of lunar distances was gaining ground, first in the East India Company and later in the Royal Navy, though it did not become routine until the nineteenth century, and even then there were continuing complaints that it was too difficult (Wess 2016). In the early years the lunar tables were, with Maskelyne's cooperation, made available to the French for translation (Howse 1996, 156–57). Subsequently, the French astronomers calculated lunar tables independently, using Paris as the prime meridian, and similarly sought to simplify the on-board calculations (Boistel 2006, 124–40; 2010, 153–57).

Determination of Longitude by Chronometer

Gemma Frisius is usually credited with proposing the most straightforward solution to determining longitude in 1530, specifically that a traveler could carry a clock holding the time of his origin so that he could simply compare the clock with observed local time. The problem was how to construct a clock that would reliably keep time with small cumulative error (two minutes of time equating to half a degree of longitude). Pendulum clocks,

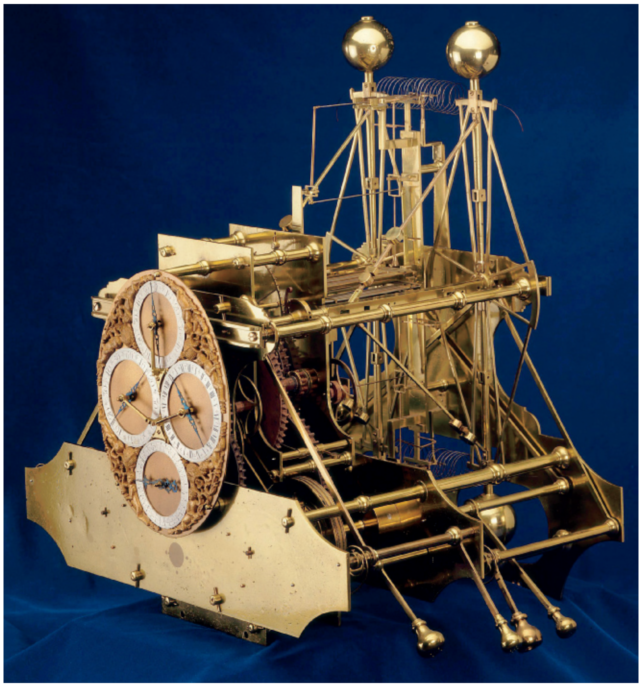

FIG. 444. JOHN HARRISON'S H.1 CHRONOMETER, COMPLETED 1735.
Height of the original: 67.3 cm. © National Maritime Museum, Greenwich, London. The Image Works.

the most accurate form of timekeeper throughout the early modern era, were ruled out for both sea and land travel. Despite many attempts, most notably between the 1650s and 1670s by Huygens (Leopold 1996), the changes in temperature and irregular motions of a moving ship caused too much error, and most observers concluded that the technological problems were insuperable; on land, such delicate instruments could not be carted around without being shaken to bits.

The clockmaker John Harrison eventually overcame the general skepticism about the use of clocks at sea (Gould 1923; Quill 1966). Having developed his initial ideas about making accurate casements without a pendulum to drive them, he went to London in 1730 in search of patronage, convincing clockmaker George Graham to support his efforts. Harrison thought that a seaborne clock could be made with compensation devices to counteract distortions from temperature change and with balanced springs rather than pendula to drive the mechanism. The first of his chronometers, H.1, was completed in 1735 (fig. 444). It worked well enough to prompt the Board of Longitude to meet formally for the first time and to vote Harrison money to continue developing his clocks. This pattern persisted for the next twenty-five years, during which time he produced three more chronometers, received support from the Board of Longitude totaling some £2,240, and was voted the Copley Medal by the Royal Society. H.1 through H.3 were large and complex machines that seemed to offer little hope of cheap production. Harrison incorporated many of his new mechanisms in a deck watch that he intended to use to carry the time from H.3 in the cabin up to the deck to compare against local time determined from solar or stellar observations. Even as Harrison found that H.3 could not meet his exacting standards, he found that his 1759 desk watch did; he soon made the watch H.4 (fig. 445). H.3 and H.4 were both tested by Harrison's son on his 1761–62 voyage to Jamaica. Despite a difficult return, H.4 lost less than two minutes over the 147-day voyage, well within the terms of the prize (King 1996; Andrewes 1996a; Randall 1996).

At this point, Harrison's work became mired in personal, institutional, intellectual, and class politics, as Sobel (1995) emphasized and as Philippe Despoix (2000) and J. A. Bennett (2002) explored more equitably. The Board wanted to ensure that H.4 was not a fluke and that it could be reproduced by other workshops; Maskelyne and the astronomers still favored the astronomical solution of lunar distances. In the end, Maskelyne tested both H.4 and Mayer's tables for lunar distance on a voyage to Barbados in 1763–64 and found that H.4 could find longitude to within ten nautical miles. Once another clockmaker, Larcum Kendall, had made a chronometer (K.1) of equal accuracy that James Cook used with resounding success on his second voyage, and Harrison had made another chronometer (H.5, completed in 1770), Harrison was finally vindicated and received his final prize awards.

Nonetheless, it was left to others to develop the man-

FIG. 445. JOHN HARRISON'S H.4 CHRONOMETER, COMPLETED 1759.
Diameter of the original: 13.2 cm. © National Maritime Museum, Greenwich, London. The Image Works.

ufacturing methods necessary to mass-produce accurate chronometers. Despite Harrison's successes, few of his specific innovations would be used, and later chronometers instead followed designs quickly pioneered in France by Berthoud and Le Roy. Harrison had proved the concept, but his specific methods were abandoned. Initially, production was slow: Kendall took several years to build K.1, while at his fastest Berthoud produced only two or three chronometers a year. Affordable chronometers were not widely available until the 1790s, when the competing businesses of John Arnold and Thomas Earnshaw charged 65–80 guineas for each timepiece. Arnold, especially, worked out methods to produce large numbers of chronometers by subcontracting the simpler parts; his chronometers were particularly favored by the East India Company, and he claimed in 1793 to have already produced more than nine hundred (Betts 1996; Cook 1985).

ADOPTION OF THE NEW TECHNOLOGIES Neither chronometers nor lunar distances were immediately heralded as *the* solution to finding longitude at sea. Chronometers were not widely found on ships until the 1790s or later, and while lunar distances were increasingly popular after the methods were simplified in the late 1760s, officials still found it easier to train new navigators than to convince more experienced ones to change their methods. Both methods presented significant problems and required further refinement and development; in 1795 the French state established its own Bureau des longitudes, which persists into the twenty-first century, primarily to continue to standardize instruments and practices (Schiavon 2016), and the Amsterdam Admiralty had a similar goal when it founded a longitude committee in 1787 (Davids 2016). Even in the early nineteenth century, navigators could still boast about not needing the new methods, although they were coming to be the exception rather than the rule.

Moreover, other techniques were not immediately abandoned. Thus, after 1758, as new technologies permitted the shortening of telescopes without reducing their power, proposals proliferated to develop stable shipboard platforms from which to observe Jupiter's satellites. The unsuccessful test in 1763 of Christopher Irwin's "marine chair" did not prevent either the British or the French from continuing to entertain proposals for similar technologies through the 1820s; indeed, one projector in 1827 argued that the use of Jupiter's satellites was made necessary because Harrison's chronometer, "in common with all others," was "liable to many imperfections" and so could not be relied on (Dunn 2012, esp. 151; Chapuis 1999, 64–67). Some French astronomers rejected lunar distances as the method of an elite (Chapuis 1999, 69) and advocated a different procedure, of calculating longitude from the ship's latitude, the meridional height of the moon, and a close approximation of the longitude; this is an iterative process, but simpler overall than lunar distances (Boistel 2002, 113–16).

In practice, chronometers required an extended technological system. Each chronometer had to be carefully studied to determine its rate, and how that rate varied over time, so that the appropriate adjustments could be made to the chronometer at sea. A major element in the work of new observatories set up in major ports after 1800 was to test and regulate chronometers, and the French worked (with limited success) to set up a system of naval observatories to synchronize chronometers (Boistel 2006, 140–48; 2010, 161–68). Also, they needed to be set to the proper time before departure. Initially, the time was determined by each navigator via astronomical observations, but the complexity of this process negated the apparent simplicity of the chronometer's use. In port, a ship could check the chronometer against the clocks at a nearby observatory, provided they carried a portable timekeeper to carry the time from the observatory to the ship. But as chronometers became increasingly important, so too did finding simple methods to set them. The solution was the time ball, first suggested by Captain Robert Wauchope of the Royal Navy as early as 1818. The idea was that a port's observatory would hoist and then drop a large ball at a specified time—often 1 P.M. so that both navigators and astronomers could make noon observations—and ships in the port could set their chronometers by noting the exact second the ball dropped. Time balls were first installed at Portsmouth in 1829 and in Greenwich in 1833, and thereafter became common throughout the British Empire (Howse 1980, 227–28; Bartky and Dick 1981).

While chronometers were generally twice as precise in determining longitude as the method of lunar distances, they remained prohibitively expensive into the nineteenth century (Howse 1996, 159). However, through the nineteenth century, it remained standard practice for captains to supply their own chronometers, in addition to any official ones, and it became increasingly common for ships to carry numerous chronometers (May 1977, 656–61). Despite the work of Berthoud and Le Roy, chronometers were not standard aboard French ships until the 1820s or even later, perhaps not even until the 1890s (Boistel 2010). In Spain, despite concerted attempts to learn the new methods (first from the English, then from the French) and produce new workshops and training programs, longitude methods were slow to spread outside of the navy (Lafuente and Sellés 1985). While it is hard to get good data on how many ships used lunar distances, the method was increasingly popular in the last decades of the eighteenth century, before being largely replaced by chronometers by the 1840s in British ships; Guy Boistel (2010) argued that lunar distances remained the preferred French technique right through the nineteenth century. But even at its most popular, far fewer books of tables were printed than ships sailed. Lunar distance tables continued to be published in both the French *Connoissance des temps* and the British *Nautical Almanac* until the first decade of the twentieth century (Howse 1996, 160–61).

ALISON SANDMAN

SEE ALSO: *Connoissance des temps*; Greenwich Observatory (Great Britain); Instruments for Angle Measuring: (1) Back Staff, (2) Octant and Sextant; Mayer, Tobias; Meridians, Local and Prime; Navigation and Cartography; Paris Observatory (France); Science and Cartography

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López de Vargas Machuca, Tomás. Tomás López was born in Madrid in 1730. After studying at the Colegio Imperial, he was sent to Paris in 1752 to learn mapmaking and engraving with his compatriot Juan de la Cruz Cano y Olmedilla, both benefiting from state funding. At the Collège Mazarin, he studied mathematics under Nicolas-Louis de La Caille, and he privately studied astronomy with Joseph-Jérôme Lefrançais de Lalande and Pierre-Charles Le Monnier and geography with Jean-Baptiste Bourguignon d'Anville. He worked with the engraver and mapmaker Guillaume Dheulland and married the daughter of the printseller Juan Carlos (Jean Charles) Gosseaume. While in Paris he engraved maps of the Gulf of Mexico and America (1755–58), a small atlas of Spain (1757), an atlas of Bohemia (1757), an atlas of America (1758), and a map that illustrates the *Guía de forasteros* to Madrid (1760) (Líter Mayayo and Sanchis Ballester 2002, 10–11; Patier 1992, 10–15).

Political change in Spain meant that, on his return in 1760, López was forced to work on his own, though he signed himself *pensionista de S.M.* (Su Majestad) on his

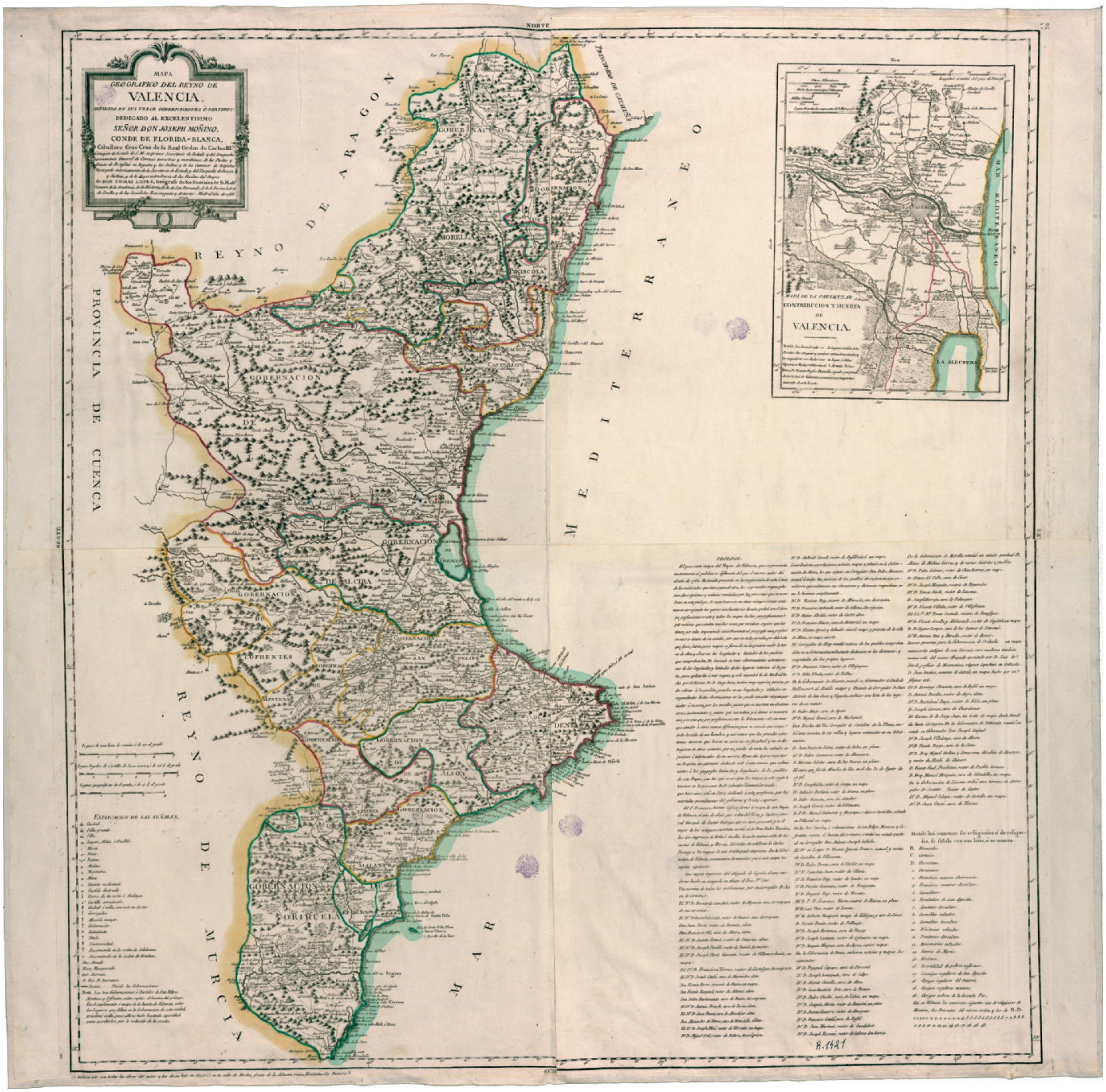

FIG. 446. TOMÁS LÓPEZ, *MAPA GEOGRAFICO DEL REYNO DE VALENCIA* (MADRID, 1788). The map contains not only an abundance of toponymic and administrative information, including the inset of the area around the city of Valencia, but also in the lower right a *prologo* comprising a full description of the sources for its compilation, including the names of individuals who provided textual accounts or detailed maps. Copper engraving in four sheets, ca. 1:360,000. Size of the original: 79 × 74 cm. Image courtesy of the Biblioteca Nacional, Madrid (GMG/300 MAPA 31).

maps of Jaén (1761), Granada and Córdoba (1761), Valencia (1762), and Madrid (1763). After 1770, a further shift in power allowed him to sign as *geógrafo de los dominios de Su Majestad*. His children, Juan and Tomás Mauricio, joined his workshop, and in 1795 he proposed the creation of the Gabinete Geográfico, for which he and Juan formed and organized the collection. López never performed surveys but gathered different sources to compile geographical maps for sale. Affirming he was a *geógrafo de gabinete*, he wrote: “A geographer works from home having in front of him various papers of the same area . . . It is not his office to draw up plans” (quoted in Líter Mayayo and Sanchis Ballester 2002, 14). As geographer to the king, he could ask for *relaciones*, responses to questionnaires, accompanied by sketches or *vueltas del horizonte*. Among his sources he lists 122 maps and 1456 informers, especially clergymen and civil authorities (Líter Mayayo and Sanchis Ballester 1998, 9) (fig. 446; and see fig. 42). The unfinished map of Spain by Jesuits Carlos Martínez and Claudio de la Vega (ca. 1740) (see fig. 320) allowed López to formulate a new plan and rework the wide-ranging and diverse documents that provided the foundation for the first cartographic coverage of Spain, not surpassed until that of Francisco Coello (1848–52).

As a scholar López wrote *Principios geográficos aplicados al uso de los mapas* (2 vols., 1775–83) and *Cosmografía abreviada: Uso del globo celeste y del terrestre* (1786), a work based on classical sources. His most ambitious project, a geographical dictionary of Spain based on the *relaciones*, was neither completed nor published. López had published some two hundred maps before his death. His work exhibited various interests: a taste for current events, such as the *Atlas abreviado de Bohemia* (1757), and a passion for ancient geography, stimulated by d'Anville, such the *Atlas elemental antiguo* (1801). López produced the *Atlas geográfico de España,* completed in 1792 and published in 1804 by his sons (Hernando 2005). Juan López, who helped his father from 1781, collaborated in this work and in various colonial maps. There exists a globe signed by López in the Biblioteca Nacional de Madrid (GM/Globo 1) (Hernando 2014, 180–82).

Critics have focused on the diversity of scales and meridians of origin (Teide and Madrid) in Spain. López represented relief by "hairy caterpillars," deduced from the hydrographic network. His lettering, both roman and italic, was clear and lithe. His contemporaries, such as Antonio José Cavanilles and Isidoro de Antillón, objected to his scant critical spirit and noted his errors, though recognizing his laborious contribution. He was a skilled engraver and popularizer, and, although he lacked innovation, he always corrected his second editions. López died in 1802.

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SEE ALSO: Academies of Science: Spain; Administrative Cartography: Spain; Geographical Mapping: Spain; Map Trade: Spain; Urban Mapping: Spain

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Lotter Family. See Seutter, Probst, and Lotter Families